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TR-1723-20

PRELIMINARY DESIGN PROGRAM FINAL REPORT

Static Feed Electrolyzer Flight Experiment Program

Prepared Under

Program No. 1682

for

Contract No. NAS8-38250-29

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LIST OF ACRONYMS

C/M I	Control/Monitor Instrumentation
CFA	Cooling Fan Assembly
CIL	Critical Items List
ECLSS	Environmental Control and Life Support Systems
EFE	ECLSS Flight Experiment
EMA	Electrolysis Module Assembly
EVA	Extravehicular Activity
FCA	Fluids Control Assembly
FE	Flight Experiment
FMEA	Failure Modes and Effects Analysis
FSA	Flight Support Accessories
HGSVA	Hydrogen Gas Sample and Vent Assembly
ICD	Interface Control Document
IN-STEP	In-Space Technology Experiment Program
ISSA	International Space Station Alpha
KSC	Kennedy Space Center
MS-DOS	Microsoft Disk Operating System
MSFC	Marshall Space Flight Center
NBT	Nitrogen Booster Tank
NSTA	Nitrogen Supply Tank Assembly
NSTS	National Space Transportation System
OGA	O2 Generation Assembly
OGSVA	Oxygen Gas Sample and Vent Assembly
ORU	Orbital Replacement Unit
PCA	Pressure Control Assembly
PDR	Preliminary Design Review
PL/M	Programming Language for Microprocessors
PO	Purchase Order
POST	Preoperational System Test
SDSU	Sensor Dedicated Shutdown Unit
SE	SFE Enclosure
SFE	Static Feed Electrolyzer
SHA	Safety Hazard Analysis
SR&QA	Safety, Reliability & Quality Assurance
SSF	Space Station Freedom
TCA	Thermal Control Assembly
TRD	Technical Requirements Document
TRHOS	Triple Redundant H2-in-O2 Sensor
TROHS	Triple Redundant O2-in-H2 Sensor
TSIP	Touch Screen Interface Panel
VIA	Vent Interface Assembly
WSA	Water Supply Assembly

INTRODUCTION

This document fulfills the requirement of the Program Plan for Contract NAS8-38250-29 to document program work in a Final Report to be identified as TR-1723-20.

Purpose

The purpose of this report is to document the Preliminary Design of the Static Feed Electrolyzer (SFE) Flight Experiment including the test protocol, SFE test hardware and the Flight Support Accessories (FSA) necessary to operate the SFE as a Flight Experiment.

Scope

This report begins with a description of how the opportunity for this experiment developed and concludes with documentation of the design produced by the program that will be implemented in the Phase C/D portion of the overall SFE Flight Experiment Program. Also, included is a basic description of the SFE Electrolysis process.

Static Feed Electrolyzer Flight Experiment Background

The SFE technology has been funded by NASA and Life Systems since 1971. The technology has progressed from single-cell test units through integrated preprototype subsystems that have been tested at NASA facilities.

In 1989 and 1990 a comparative test of electrolyzer technologies was conducted at the Marshall Space Flight Center (MSFC) in Huntsville, Alabama. As a result of this test, Life Systems SFE was selected for use on the Space Station Freedom (SSF) and a Space Station design contract was issued through Boeing. This contract proceeded through a PDR. Soon after completion of the PDR, the Space Station Program was restructured and closure of the O_2 loop was deferred. As a result of this deferral, SFE work was placed on hold.

The next significant event was the change from SSF to International Space Station Alpha (ISSA). Of significance in this change was that the O_2 generator operation was changed from continuous to cyclical to match the light-dark cycle of the orbit which required modifications to the SFE hardware design and control software. The change from continuous to cyclical operation of the O_2 generator introduced a requirement that the O_2 generator be capable for rapid transitions from inactive operation (Standby Mode) to active operation (Normal Mode) so that maximum utilization of the 53 minute sunlight period of the orbit can be achieved. This requirement did not previously exist and emphasis was placed on long-term continuous operation.

In recognition of this change, MSFC decided to modify an item of O_2 generator development hardware to operate in the cyclic mode. The item selected for modification was the SFE-IVA, illustrated by Figure 1. The SFE-IVA had been provided by Life Systems for use in the Preoperational System Test (POST). The contract issued for this conversion included hardware and software modifications to incorporate cyclic operation and to implement performance approaches identified as necessary by the comparative test. Extensive test data from operation of the upgraded SFE-IV, designated the SFE-IVA' will be available to support the final design of the SFE Flight

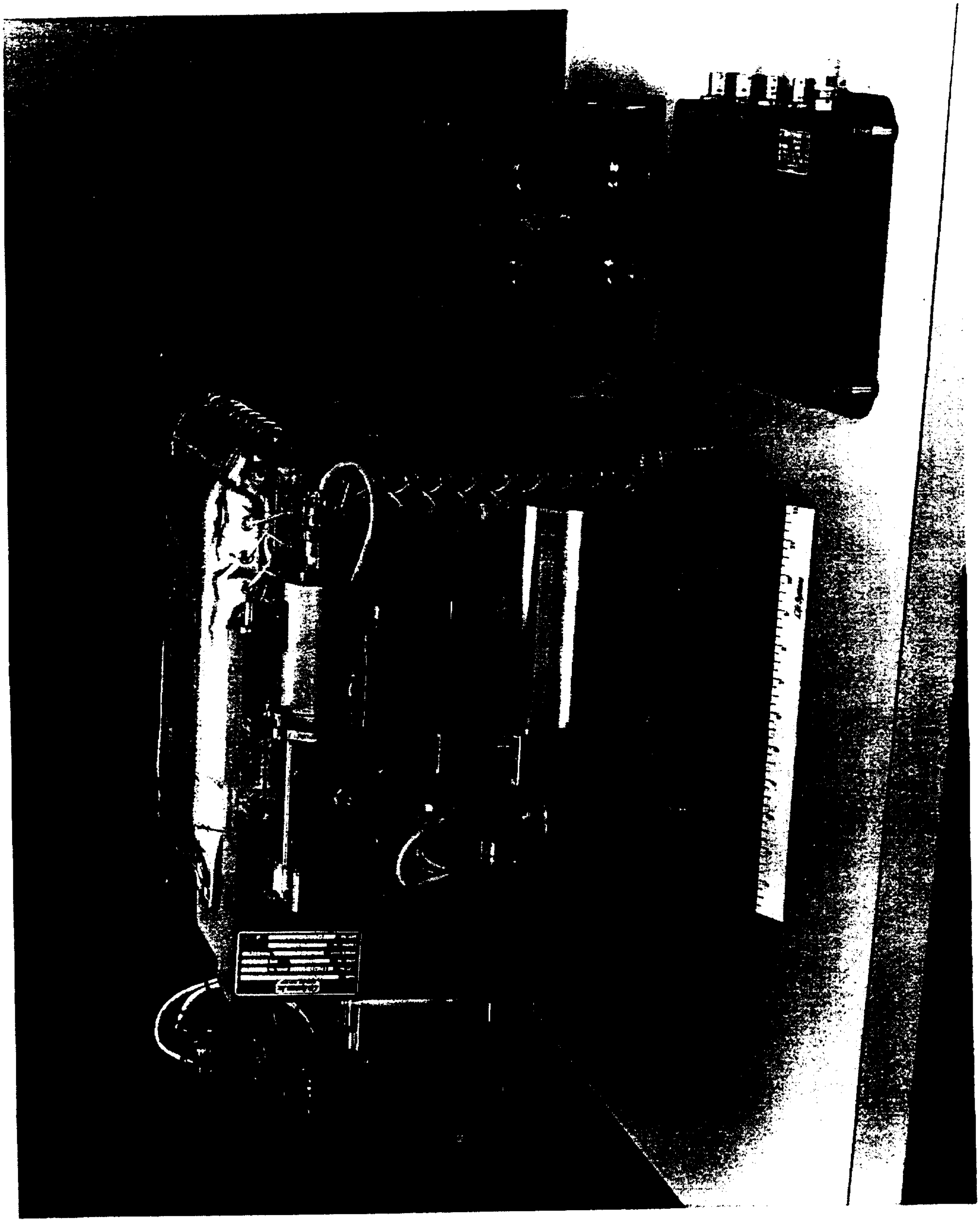


FIGURE 1 SFE-IVA STATIC FEED ELECTROLYZER

Experiment which will incorporate the new features being demonstrated by the SFE-IVA'. When shipped to MSFC on April 28, 1995, the SFE-IVA' had successfully accomplished 577 cycles of test operation.

Closure of the O_2 loop for ISSA was still deferred to later in the program. At this point it was recognized that it was possible to implement a Flight Experiment that would demonstrate the operation of an integrated SFE subsystem in microgravity and significantly reduce the risk of using the SFE on ISSA.

This opportunity was identified by NASA and, with the sponsorship of MSFC within NASA, a Flight Experiment program was initiated. This program was structured as a two-phase process. The first phase was structured to define the experiment and complete design work through a Preliminary Design Review (PDR). The second phase is to implement the design documented by the Preliminary Design through a flight test in either the MIR, Spacelab or SPACEHAB flight platforms. The SPACEHAB has been identified as the flight vehicle to be used.

Static Feed Electrolyzer Technology Background

Advanced space missions will require O_2 and hydrogen (H_2) utilities for several important operations including: (1) environmental control and life support; (2) propulsion; (3) electric power generation and storage; (4) extravehicular activity (EVA); (5) in-space manufacturing activities; and (6) in-space science activities. A key to providing these utilities for advanced space missions will be to minimize resupply from earth requirements and initial earth to orbit launch mass. Static Feed (Water) Electrolysis technology, using an alkaline electrolyte, has been recognized as a design capable of efficient, reliable O_2 and H_2 generation with few system components. Figures 2 and 3 illustrate the Static Feed Water Electrolysis process. Figure 4 illustrates the use of the SFE technology as a space exploration utility. The static feed concept has evolved over the last 25 years under the NASA and Life Systems, Inc. (Life Systems) sponsorship. During this time the concept has progressed from single-cell operation through the fabrication and testing of multiperson subsystems (for life support) culminating in the selection of an SFE-based O_2 Generation Assembly (OGA) for the Air Revitalization System aboard the Space Station Freedom.

Recent developments at Life Systems have demonstrated substantial reduction in the operating voltage of the electrolysis cells and have allowed for the consolidation of ancillary components resulting in the reduction of power, weight, volume and complexity. The overall impact of these state-of-the-art advancements is significant since the OGA is a large power consuming subsystem of a regenerative life support system and even more significant when considering advanced mission scenarios which require tons of O_2 production per year for propellant.

Major breakthroughs/improvements have also been made on electrode performance, cell design, module construction, integrated ancillary mechanical components, packaging, maintainability and Control/Monitor Instrumentation (C/M I). These breakthroughs/improvements are well documented in final reports, technical papers and Life Systems' engineering reports. Figure 5 illustrates the overall advancement of the SFE technology.

Extensive endurance testing of the SFE hardware has shown that the operation of the electrolysis module gives long life with little cell degradation. Endurance test hours that have been achieved within Life Systems' endurance testing program include one cell (Cell 105C) operating continuously (noncyclically) for over 45,000 hours (five years). Converting the cumulative 46,000 hours of

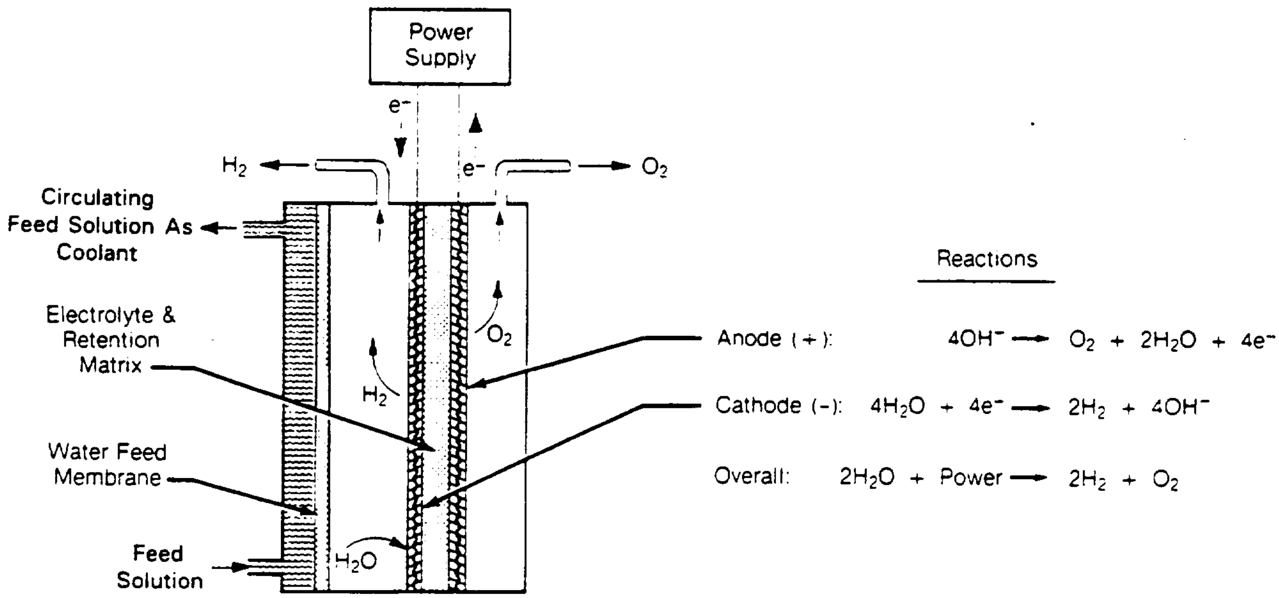


FIGURE 2 ELECTROLYZER CELL SCHEMATIC AND REACTIONS

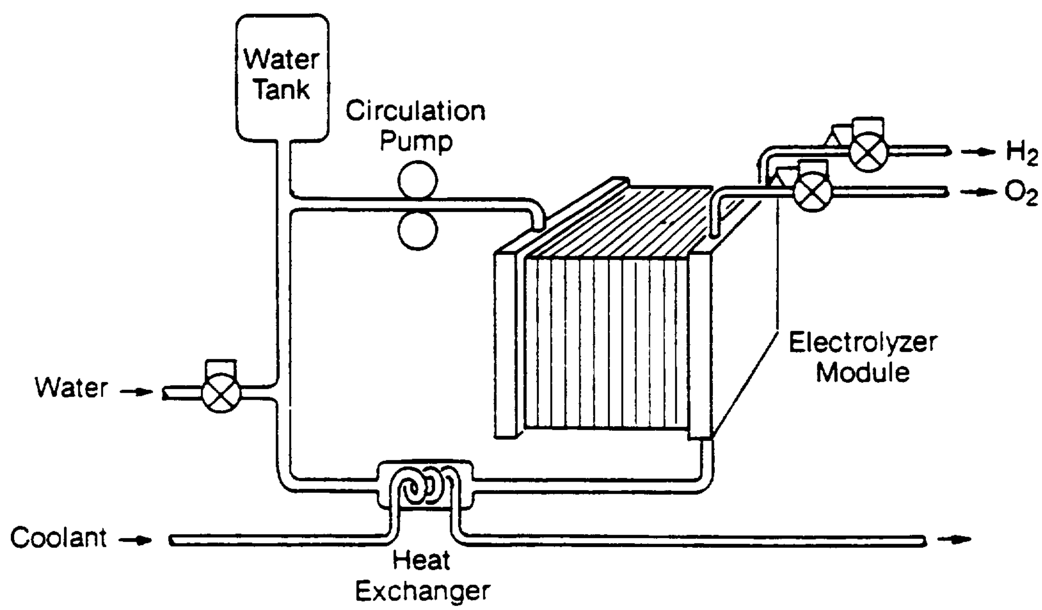


FIGURE 3 SIMPLIFIED SFE PROCESS SCHEMATIC

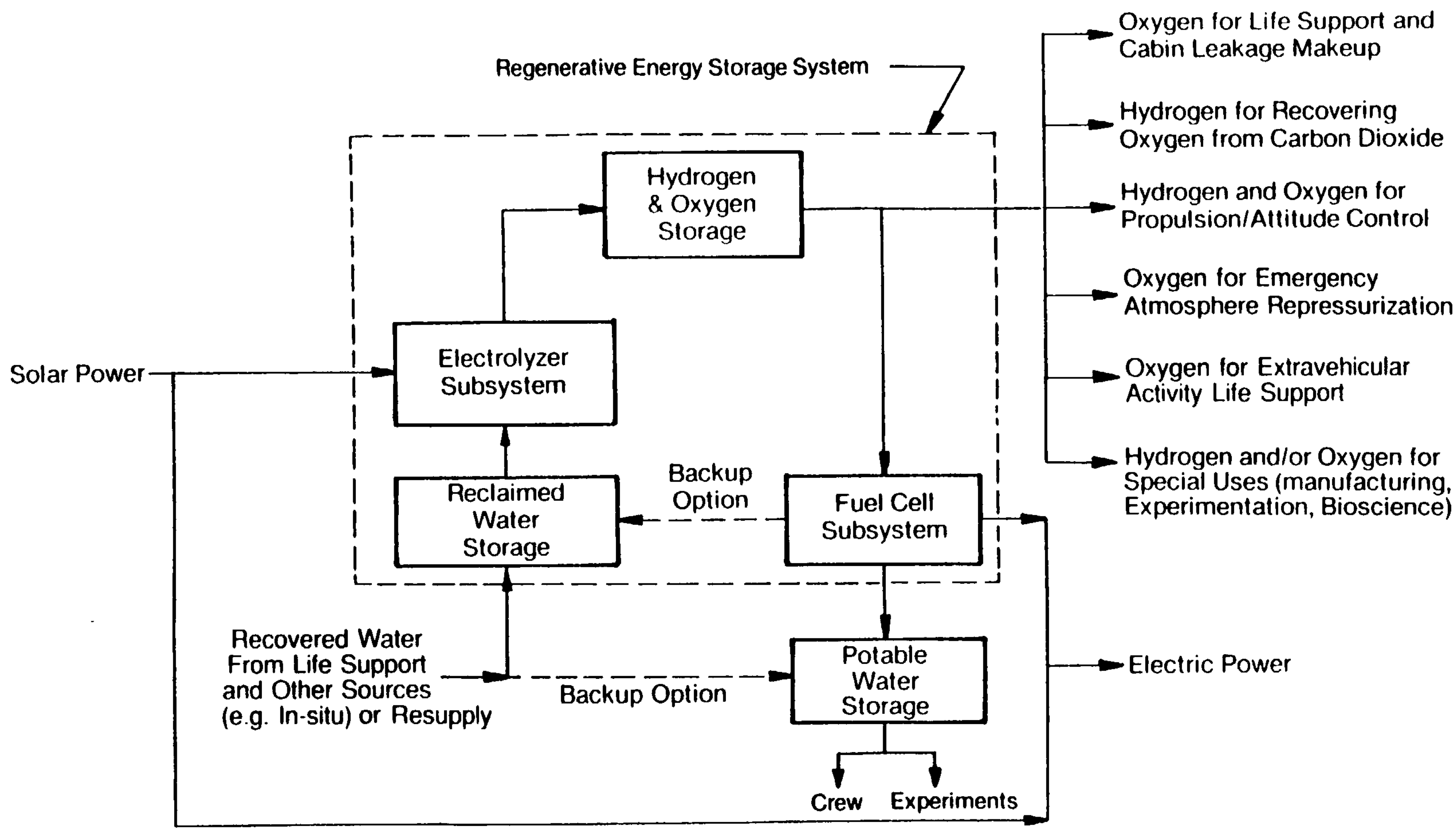
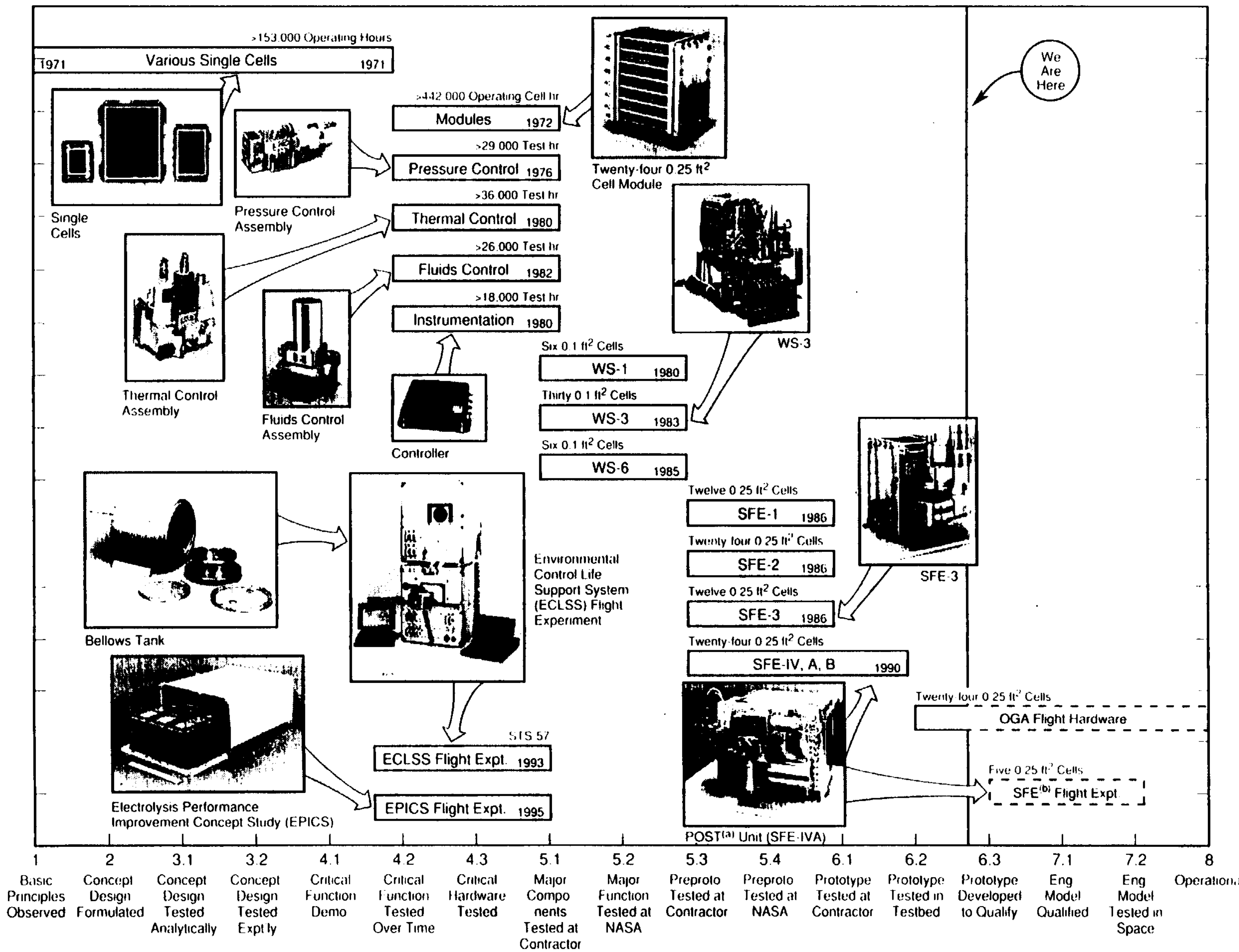


FIGURE 4 STATIC FEED WATER ELECTROLYSIS - A MANNED SPACE EXPLORATION UTILITY



(a) POST = Predevelopment Operational System Test
(b) SFE = Static Feed Electrolyzer

FIGURE 5 TWENTY-THREE YEARS DEVOTED TO TAILORING THE OGA TO SPACE STATION APPLICATIONS operation to cyclic time results in over 74,000 hours (over eight years each) of Space Station equivalent life. In addition two single cell modules (Cell 105B and 105D) operated cyclically, simulating low earth orbit conditions for 45,000 and 44,000 hours, respectively.

The inherent simplicity of Life Systems' electrolysis module design is directly responsible for these results. The static water addition concept of the SFE, for example, separates the feed water from the cell electrolyte eliminating electrode catalyst contamination. The extensive endurance testing has shown that the operation of the SFE will meet long-life requirements without cell degradation. There are no moving parts within the module stacks. Multicell modules have been built and tested with 0.1 ft^2, 0.25 ft^2 and 1.0 ft^2 active individual cell areas.

Several systems have been built and tested for application to Environmental Control and Life Support Systems (ECLSS) and the regenerative fuel cell. Figure 6 pictorially illustrates how the SFE has matured, reducing size and complexity, while improving performance and reliability. Past efforts include a Regenerative Fuel Cell System, a 4-person ECLSS OGA for the NASA Space Station Technology Demonstrator Program and high pressure gas generation applicable to propellant generation or EVA O_2 bottle recharge, as shown in Figure 7.

The effect of microgravity on SFE performance is difficult to predict on the basis of ground tests alone. It is expected that some aspects of performance may actually be enhanced by microgravity, but there is concern that other aspects may be hindered. One In-Space Technology Experiment Program (IN-STEP) experiment will examine the effects of microgravity on specific subcomponents of the SFE electrolysis cell.

This In-Step flight experiment, currently in Phase C/D will examine the effects of microgravity on electrolyte distribution in the SFE electrolyte retention matrix and in the electrodes. The experiment will determine performance characteristics of electrode/matrix assemblies having different matrix thicknesses and electrode pore sizes. Results of this experiment will be taken into account in development of the flight demonstration system proposed here. Nonetheless, there is no work in progress to determine the overall performance of the electrolysis subsystem in microgravity. Without system testing in the flight environment, it is impossible to be confident that all microgravity sensitivities of the SFE have been identified and controlled. This flight experiment will serve to identify SFE components, if any, which require modification for microgravity operation and will provide confidence in the readiness of the SFE technology to provide O_2 for crew life support.

PROGRAM OBJECTIVES AND SCOPE

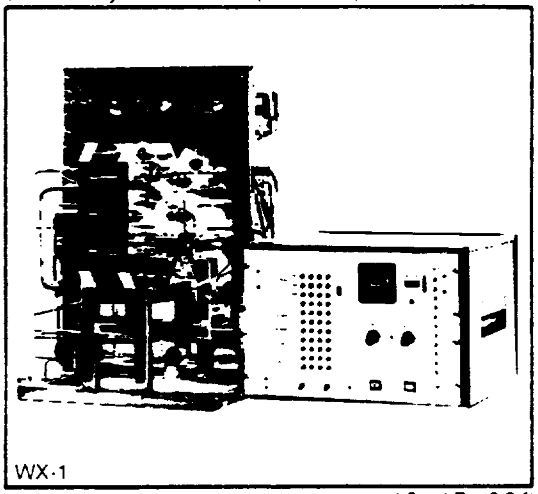
Flight Experiment Objectives

The overall objective of the SFE Flight Experiment is to demonstrate the readiness of the technology for use in long duration space missions as a water electrolysis based utility. Specifically, the objectives of the experiment are to:

1. Evaluate the microgravity sensitivity of all SFE System components and processes on an integrated basis.

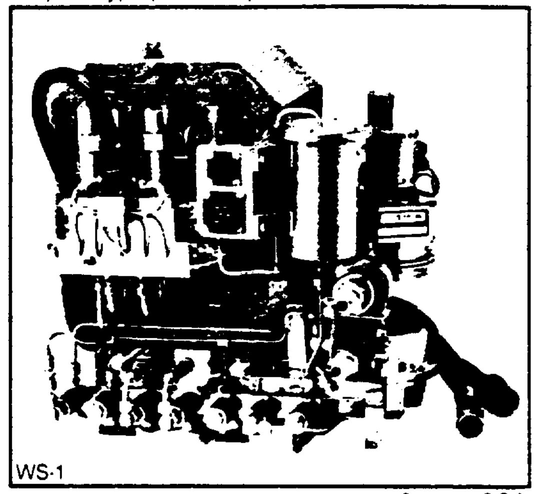
    a. Validate ground-based analyses
    b. Validate multiple-cell configuration behavior

Laboratory Breadboard (1 Person)



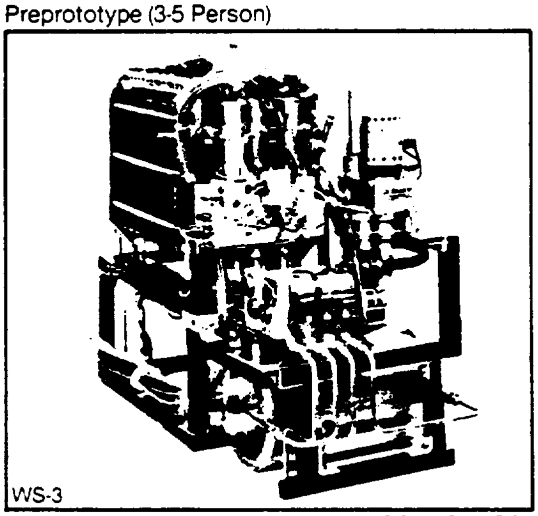
1.5 x 1.7 x 2.3 ft

Preprototype (1 Person)



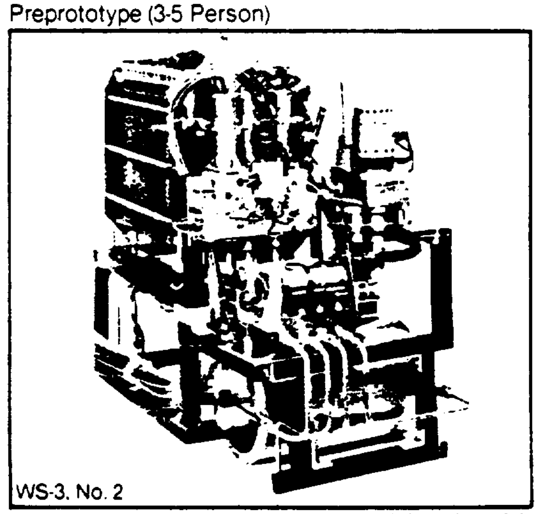
1.2 x 1.4 x 0.9 ft

Preprototype (3-5 Person)



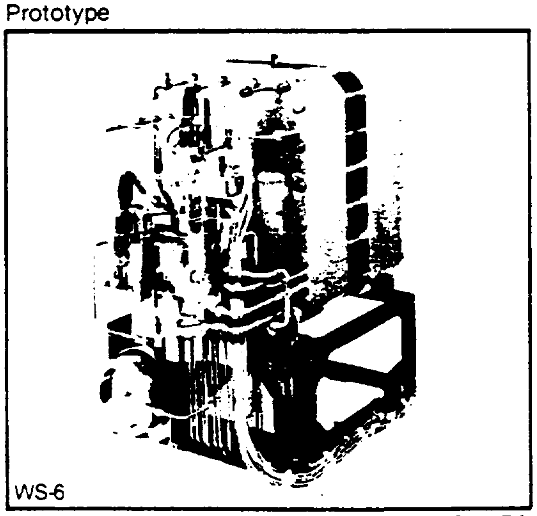
0.9 x 1.8 x 1.9 ft

Preprototype (3-5 Person)



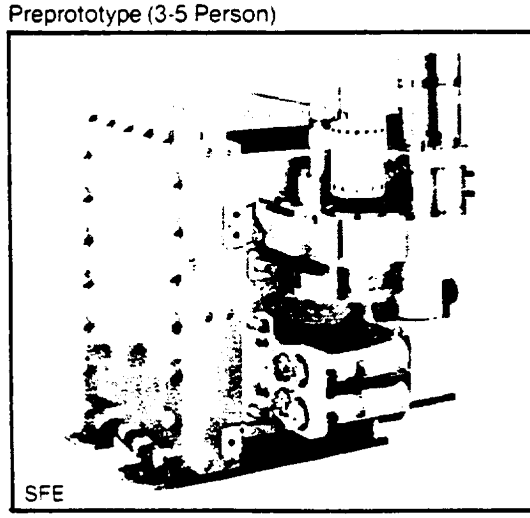
0.9 x 1.8 x 1.9 ft

Prototype



1.3 x 1.9 x 1.7 ft

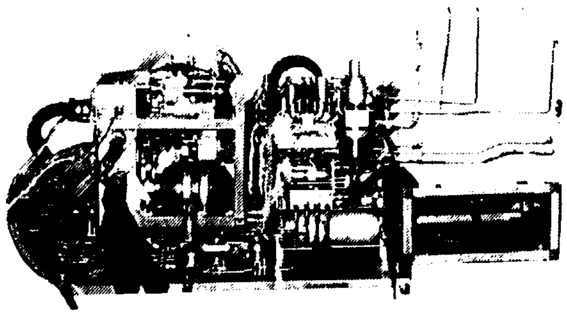
Preprototype (3-5 Person)



1.3 x 1.3 x 1.0 ft

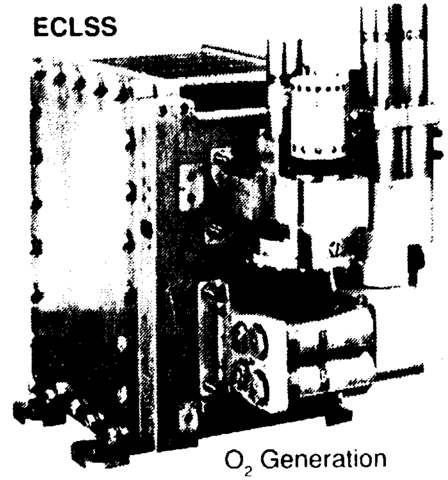
FIGURE 6 STATIC FEED ELECTROLYSIS TECHNOLOGY IS MATURE

Power Storage



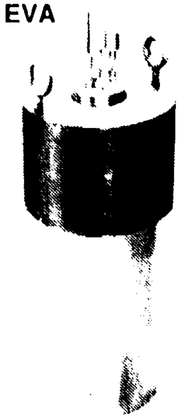
Regenerative Fuel Cell

ECLSS



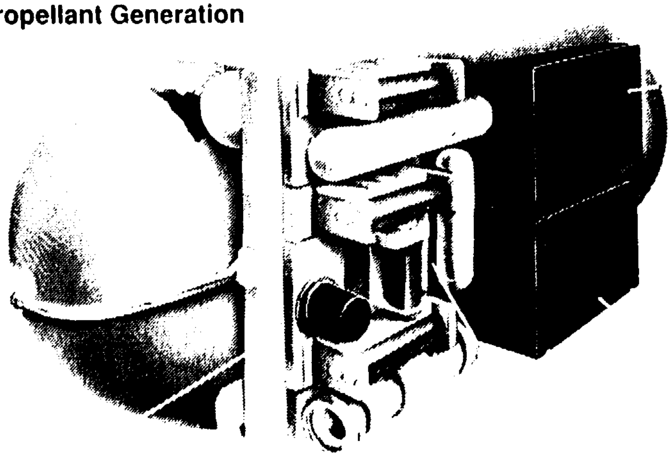
O_2 Generation

EVA



6,000 psi O_2 Generation

Propellant Generation



High Pressure O_2/H_2

NASA Center	Application
Johnson Space Center	Propulsion and Power Life Support EVA
Marshall Space Flight Center	Propulsion Life Support
Lewis Research Center	Power
Ames Research Center	Life Support

FIGURE 7 POTENTIAL SFE APPLICATIONS

2. Verify the performance of the integrated SFE System in microgravity

   a. Validate the entire SFE concept at the systems level
   b. Validate the interaction of component parts
   c. Validate quality and quantity of product gases
   d. Validate SFE efficiency

The objectives of the Preliminary Design program are to:

1. Define an experiment that, if successfully performed, accomplishes the program objectives stated above and

2. To develop and document a design through a PDR that can be efficiently implemented into hardware and qualified for flight.[a]

Justification for Conducting the SFE Flight Experiment

The Introduction of this document has defined the extensive earth based testing that has lead to the current development status of the SFE technology. The Introduction has also identified the many opportunities for application of this technology as a key building block utility for long duration space missions.

The next step in the development of the technology is its demonstration as a fully-integrated subsystem in a microgravity environment. Testing in a microgravity environment will confirm the extensive analyses that indicate the integrated subsystem design will successfully operate in microgravity. Specific aspects of microgravity flight that are of special interest are the distribution of fluids, particularly within the electrochemical module, and the elimination of buoyancy affects on gas/liquid interfaces that will exist in microgravity.

Alternate microgravity testing approaches, e.g., drop towers of parabolic flight paths, are not appropriate for testing of the SFE technology due to their very short test times. Therefore, the only means to fully demonstrate the technology is by on-orbit testing in a manner like that offered by this planned Flight Experiment.

Flight Experiment Scope

The scope of the complete SFE Flight Experiment program begins with definition of the experiment and is completed with analysis of the test data generated by the in-space testing of the fabricated experiment in the SPACEHAB vehicle.

The program is structured into two distinct phases. The first is a Preliminary Design study that begins with definition of the experiment and ends with completion of a PDR. the second phase completes the experiment. It begins with the Preliminary Design being converted into a detail design for fabrication and ends with an analysis of the data generated by the operation of the experiment in space.

This report documents the results of the Preliminary Design program.

(a) During the program effort, the target flight vehicle was identified as the SPACEHAB.

Flight Experiment Success Criteria

The SFE Flight Experiment will be successful if it verifies the current design of the SFE or identifies modifications necessary to achieve reliable operation in space. The SFE Flight Experiment will be fully successful if it operates through the baseline four-day test program and its performance meets or exceeds earth testing performance parameters. If the extra two days of operation are also achieved, it will be a bonus. The minimum acceptable level of performance would be establishment of steady-state operation in normal mode. If steady state operation is achieved, even if performance is below expectations or operational problems occur, there will be sufficient data generated to diagnose problems and/or uncover any inherent weakness in the SFE design. This will enable the hardware to be upgraded prior to future use. The means by which data is to be utilized to analyze the performance of the SFE Flight Experiment is shown by Table 1. Table 2 defines how specific performance evaluations are to be achieved.

Benefits

There are two major benefits that can be derived from the success of this project. The first is that the knowledge gained will significantly reduce the development risk that would exist if extended micro-gravity testing is not achieved before the SFE technology is used on the ISSA. The second benefit is that flight tested hardware will be available that could be used either directly on the ISSA or as part of a ground test bed to support ISSA. This hardware would be available at an early date for use as best needed.

STATIC FEED ELECTROLYZER FLIGHT EXPERIMENT DESIGN DESCRIPTION

Test operation of an SFE in either an earth-based or flight experiment microgravity laboratory requires both the SFE test article and the hardware to simulate the interfaces necessary for the operation of an SFE that would be available with operation in an integrated system. Therefore, the SFE Flight Experiment design is separated into two groups of hardware and software. The first group is that hardware and software that represents the fully integrated SFE subsystem. This is the hardware and software that represents the SFE subsystem that wold fly onboard the Space Station. The second group of hardware and software is that hardware and software that simulates the interfaces that an SFE would see in operation onboard the Space Station. This group of hardware and software has been given the designation of FSA. Together both groups make up the Flight Experiment. Each group and their function are described in the following sections.

Design Configuration

The following sections define physical characteristics of the experiment hardware, including description of the individual components that make up the Flight Experiment design.

Mechanical Schematic with Sensors

The mechanical schematic with sensors of the SFE is shown by Figure 3-1. As described, the experiment consists of the SFE shown on the left of the schematic, and FSA, shown on the right side of the schematic.

The SFE takes feedwater from the FSA and generates H_2 and O_2 which are returned to the FSA for sampling or venting. Nitrogen (N_2) is supplied to the SFE from the FSA for purging and

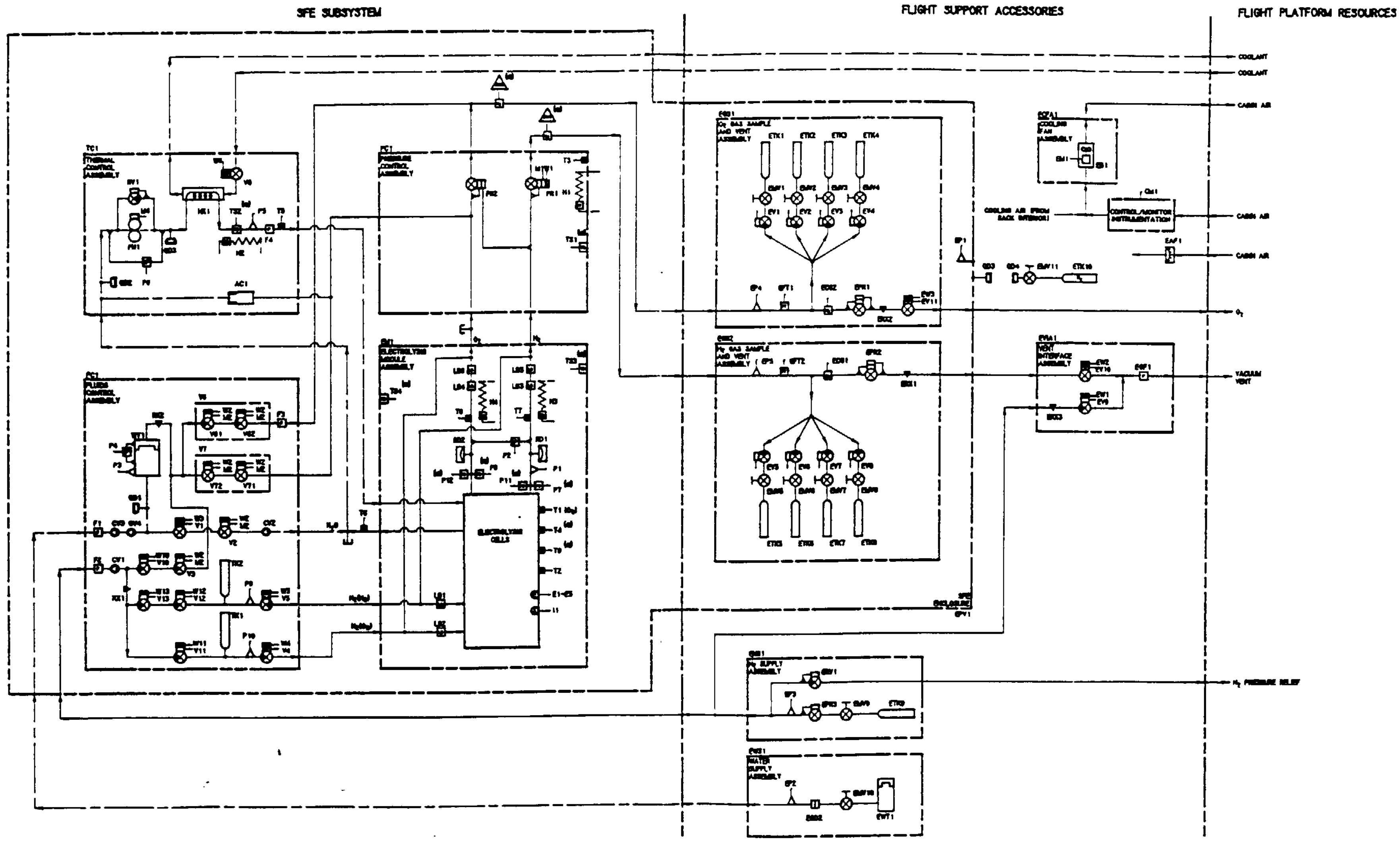
TABLE 1 TEST DATA DEFINITION[(a)]

	Flow Rate				Temperature						Pressure													Quantity		Quality			Power	
	O_2 Vent (EFT1)	H_2 Vent (EFT2)	N_2 Supply (EP3)	Water Supply (EP2)	O_2 Outlet (T1) SDSU	Electrolysis Module (T2, T4 & T9)	Liquid to Module (T5)	Liquid from Module (T6)	Pressure Control Assembly (T3)	Barrier Cells (T7 & T8)	O_2 Outlet (P1 and P2)	H_2 Outlet (P1)	O_2 to H_2 Pressure Differential (P2)	Water Tank (P3 & P4)	Module Coolant (P5)	Thermal Control Assembly Pump ΔP (P6)	N_2 (H_2 Side) (P9)	N_2 (O_2 Side) (P10)	Pressure Vessel Assembly (EP1)	Water Supply Pressure (EP2)	N_2 Supply Pressure (EP3)	O_2 Vent (EP4)	H_2 Vent (EP5)	Water Supply Assembly (EP2)	N_2 Supply Assembly (EP3)	Samples	H_2-in-O_2 (CG2)	O_2-in-H_2 (CG1)	Cell Voltage (E1-E5)	Current (I1)
1. Verify Integrated Operation:																														
• O_2 Production Rate	P																							X			X	X		P
• H_2 Production Rate		P																						X			X	X		P
• Power Consumption							X	X	X	X														X					P	P
• O_2 and H_2 Quality																										P	X	X		
• Dynamic Response	X	X									P	P	P																P	X
• Modes/Mode Transitions[(b)]			X			X	X	X			X	X	X	X		X	X	X				X	X		X	P	X	X		
2. Verify Unscheduled Shutdown and Restart Capability	X	X				X	X	X			X	X	X				X	X											X	X
3. Verify Tolerance to Launch Conditions	X	X									X	X	X	X					X							P	X	X	P	X
4. Characterize Multi-Cell Configuration Behavior	X	X																								P	X	X	P	X
5. Validate Ground-Test Analysis	P	P	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		P	P	P	P	P

(a) P = Primary data required; X = Supporting data required.
(b) Verify normal operation of firmware and hardware.

TABLE 2 TEST DATA ANALYSIS

Purpose of Data	Analysis Approach
1. Verify Integrated Operation:	
• H_2 Production Rate	• Flight Unit Mass Balance; Comparison with Earth Testing
• O_2 Production Rate	• Flight Unit Mass Balance; Comparison with Earth Testing
• Power Consumption	• Cell Voltages and Heater Power; Comparison with Earth Testing
• O_2 and H_2 Gas Quality	• Flight Data comparison with Earth Data
• Dynamic Response	• Major Parameter Transients Compared with Earth Data
• Modes/Mode Transitions	• Major Parameter Transients Compared with Earth Data
2. Verify Unscheduled Shutdown and Restart Capability	• Major Parameter Transients Compared with Earth Data • Steady State Parameter Values Comparison Before and After Unscheduled Shutdown and Restart • Product Gas Sample Comparisons Before and After Unscheduled Shutdown and Restart
3. Verify Tolerance to Launch Conditions	• Major Parameter and Transient Values Compared to Earth Testing (After Reaching Orbit, Nonoperational During Launch) • Functional Verification of Sensors and Actuators
4. Characterize Multi-Cell Configuration Behavior	• Cell to Cell Voltage Comparisons • On Orbit Versus Earth Testing Cell Voltage Comparison • Gas Sample Comparisons from Earth to On Orbit Testing
5. Validate Ground Test Analyses	• Major Parameter Values Compared to Earth Testing • Major Parameter Transients Compared with Earth Data • Gas Sample Analyses Compared to Earth Values



(a) Used by Sensor Dedicated Electronic Units (SDEUs)

FIGURE 8 MECHANICAL SCHEMATIC WITH SENSORS

LEGEND

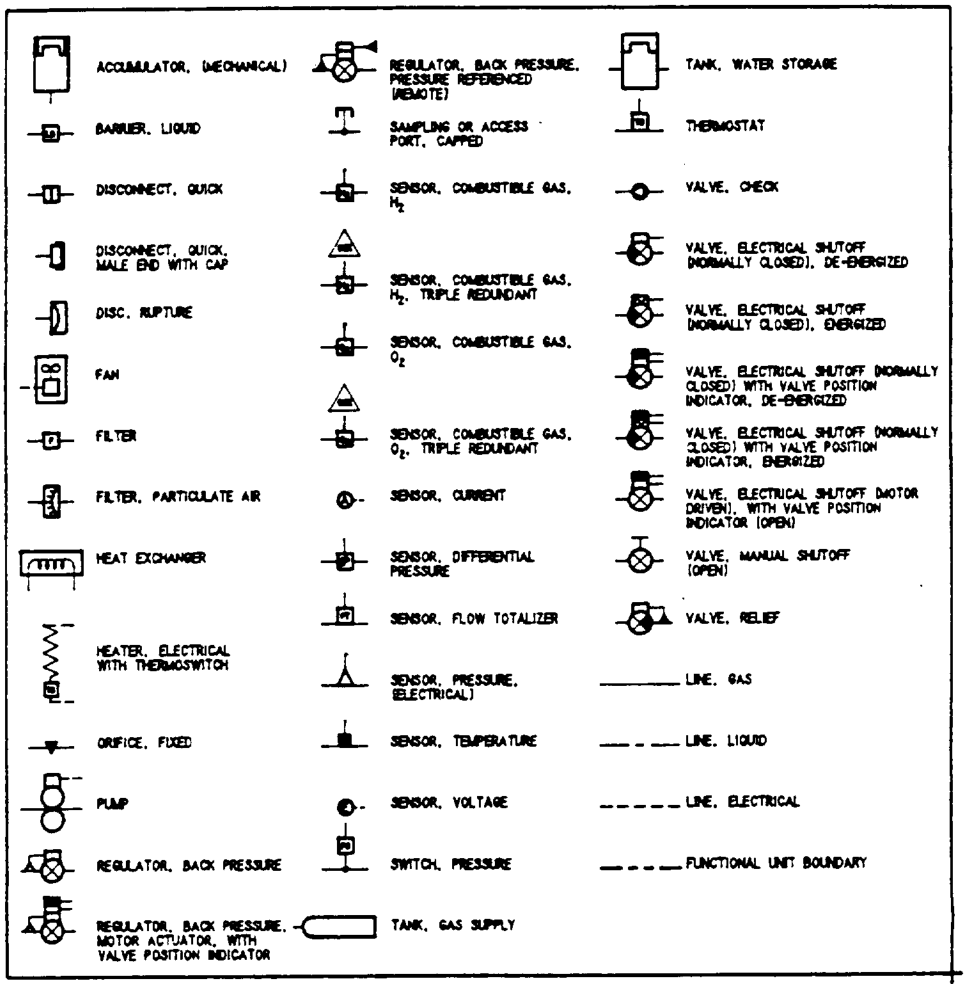


Figure 8 - continued

pressurization. Avionics cooling air is provided by the FSA by drawing cabin air into the rack and rejecting it to the SPACEHAB subfloor. Compliance with National Space Transportation System (NSTS) safety requirements is provided by the SFE Enclosure Assembly which encloses the SFE in a pressurized N_2 environment (N_2 pressure greater than SFE operating pressure).

Static Feed Electrolyzer Component Descriptions. The configuration of the SFE for flight testing was defined by Trade Study No. 1 documented in Life Systems' report TR-1723-4, Trade Studies and Rationale for Flight Experiment Configuration. This study defined a system with an O_2 generation rate equivalent to a single person. This requires an electrolysis module with five (5) full size SFE cells, equivalent to those being tested in the SFE-IVA'. An SFE based on a five-cell module is small enough to provide operation within the resource restraints of the SPACEHAB and large enough to provide representative testing of the module, particularly on a thermal basis since five cells provide a sufficient thermal mass to minimize end effects.

In addition to the use of full-sized electrolysis, other components of the SFE are to be full sized (i.e., the same size that would be used on the SFE-based oxygen (O_2) generator for ISSA). However, the water tank to be utilized with the Fluids Control Assembly (FCA) will be reduced in size to simulate the ISSA water fill cycle frequency while operating with a five-cell module. Therefore, with the use of full-sized components, the SFE Flight Experiment could be converted for full capacity use in the ISSA program by increasing the number of cells in the electrolysis module and replacing the water tank on the FCA. Each of the SFE mechanical subassembly components are described below:

- Electrolysis Module Assembly (EMA)

  The EMA consists of the electrolysis module, main interface plate and the adaptor plate. The electrolysis module electrochemically dissociates water into O_2 and H_2. The electrolysis module consists of five (5) electrochemical cells, each of 0.25 ft^2 active electrode area. The main interface plate provides fluid interfaces and structural mounting supports for other Orbital Replacement Units (ORUs). The adaptor plate provides an interface between the main interface plate and external plumbing.

- Pressure Control Assembly (PCA)

  The PCA monitors and maintains the SFE operating pressure and the differential pressures between the O_2, H_2 and water cavities of the electrolysis module.

- Fluids Control Assembly (FCA)

  The FCA supplies water to the electrolysis module via a pressurized, cyclically filled water supply tank. The FCA provides a secure N_2 supply for pressure maintenance in Standby and emergency purging. Valving within the FCA, controlled by C/M I, controls the flow of fluids to the electrolysis module as required for operation.

- Thermal Control Assembly (TCA)

  The TCA circulates feed solution through the electrolysis module feed compartment to control water feed to the cells of the electrolysis module and to control electrolysis module operating temperature. Waste heat is rejected to SPACEHAB coolant. Startup heat is generated by a heater within the TCA.

- Triple Redundant O_2-in-H_2 Sensor (TROHS)

  The TROHS detects the presence of O_2 in the H_2 stream. The TROHS operates through a Sensor Dedicated Shutdown Unit (SDSU) to shutdown the experiment if leakage is discovered by removal of power.

- Triple Redundant H_2-in-O_2 Sensor (TRHOS)

  The TRHOS detects the presence of H_2 in the O_2 stream. The TRHOS operates through a SDSU to shutdown the experiment if leakage is discovered by removal of power.

Flight Support Accessories Component Descriptions. The FSA consist of the following seven (7) major components:

- Nitrogen Supply Tank Assembly (NSTA)

  The NSTA provides N_2 to the SFE for pressurization and purging of product O_2 and H_2 gases. The NSTA also provides purge N_2 for the vacuum vent.

- Water Supply Assembly (WSA)

  The WSA provides water to the Electrochemical Module through the FCA for electrolysis into product O_2 and H_2 gases. An internal bellows provides positive water pressure to the SFE.

- Hydrogen Gas Sample and Vent Assembly (HGSVA)

  The HGSVA provides the means for collecting four (4) 100 cc H_2 gas samples during the experiment for detailed analysis upon return to earth. Sample taking is fully automated. It also provides H_2 flow monitoring and backpressure control.

- Oxygen Gas Sample and Vent Assembly (OGSVA)

  The OGSVA provides the means for collecting four (4) 100 cc O_2 samples during the experiment for detailed analysis upon return to earth. Sample taking is fully automated. It also provides O_2 flow monitoring and backpressure control.

- Cooling Fan Assembly (CFA)

  The CFA draws air from the SPACEHAB environment through the rack front panel and the C/M I. The CFA discharges to the SPACEHAB subfloor. It provides the cooling function of avionics air.

- SFE Enclosure (SE)

  The SE provides a means for insuring safe operation of the experiment. The SE surrounds the experiment in a pressurized N_2 gas environment. The SE is designed to contain the energy released if an explosion were to occur within the SFE.

- Nitrogen Booster Tank (NBT)

  The NBT provides a means of adding additional N_2 to the SE if needed to maintain the desired operating pressure.

- Vent Interface Assembly (VIA)

  The VIA provides the protections required for an experiment to interface with the SPACEHAB vacuum vent.

Control/Monitor Instrumentation

Operation of the Flight Experiment is to be fully automated through C/M I. Two separate C/M I's are to be utilized in the experiment. The first is that which controls the SFE and is designated the Model 560 C/M I. The Model 560 C/M I represents the C/M I that would control the SFE when implemented on the Space Station. The second is that which controls the overall experiment and the FSA and is designated the Model 686 C/M I. This C/M I monitors the FSA instrumentation controls. the FSA actuators and provides command signals to the Model 560. It provides the crew interface and the mass storage of experiment operating data. Figure 9 illustrates the relationship of the C/M I's by showing the electrical block diagram of the Flight Experiment. Both C/M I's are packaged within a single enclosure. Each C/M I component is described below.

- Model 560 Control/Monitor Instrumentation (Model 560 Controller)

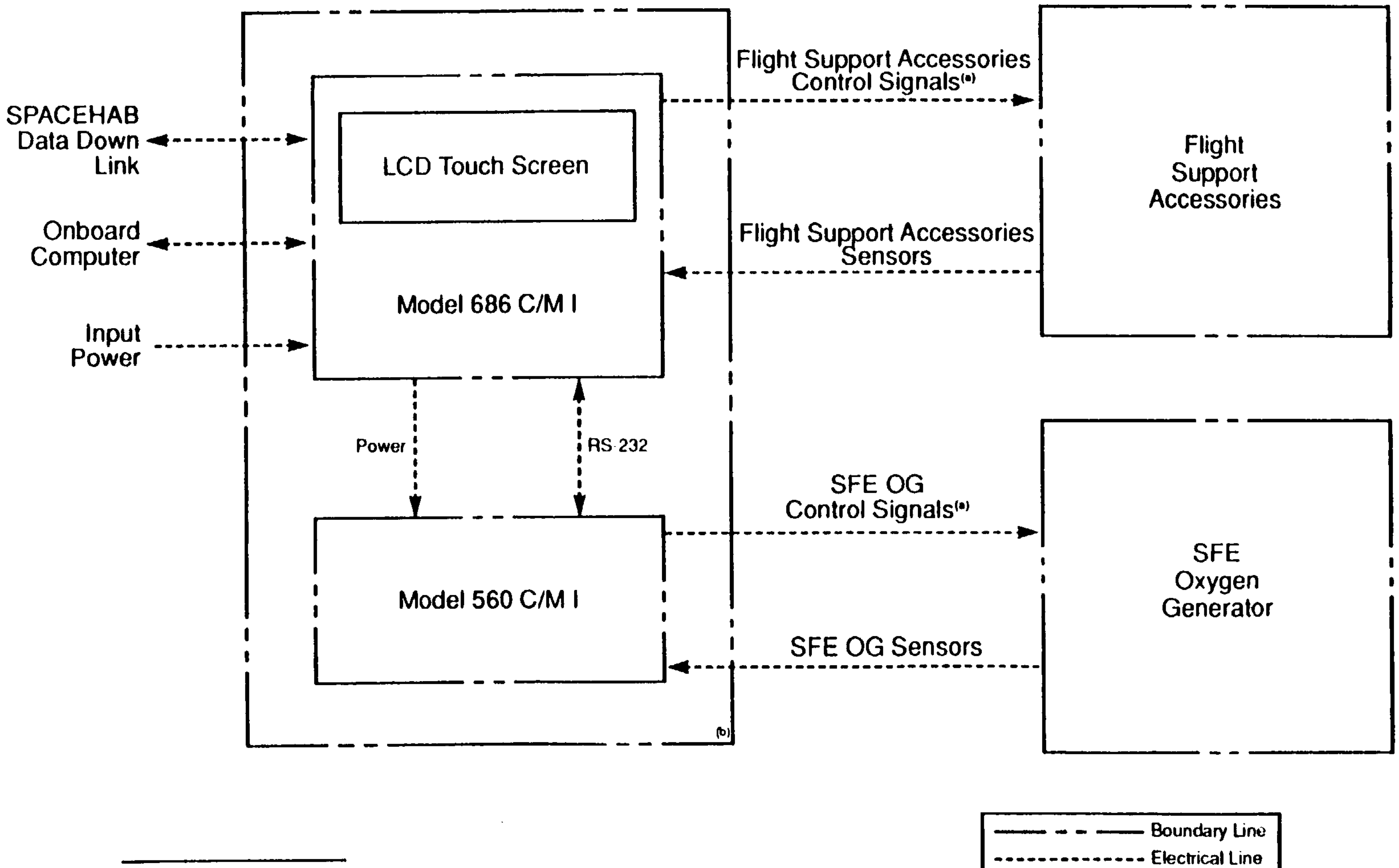
  The Model 560 Controller provides monitoring and control of the SFE portion of the experiment. The controller includes the computer processing, generic sensor, special sensor and actuator signal conditioning as well as power protection and conversion functions required to automatically control the SFE subsystem. The signal conditioning includes both controlling power to the actuators and processing sensor signals from the mechanical subsystem. The SFE Current Controller is part of the Model 560 controller. The SFE control software resides in the Model 560 Controller. The major functions of the software are to implement modes of operation, perform process control and provide for fault detection.

- Model 686 Control/Monitor Instrumentation (Model 686 Controller)

  The Model 686 Controller provides experimental test sequencing, data logging/storage, power distribution, flight experiment/flight vehicle communications and crew interface. The controller includes computer processing, sensor and actuator signal conditioning, special power drivers, power conversion and touch screen display and keyboard interface functions required to control the flight experiment. A standard RS-232 communication bus to the Model 560 Controller provides intra-experiment control and data transfer. Additional capabilities include a communication link to the SPACEHAB for downlinking of data and a communication link to the onboard lap top computer and single sensor shutdown of the experiment for safety.

Experiment Packaging

The SFE Flight Experiment is designed to be packaged in a SPACEHAB double rack. (It can also be adapted for use in a Spacelab double rack.) The Flight Experiment Assembly is packaged and



(a) Includes power for sensors/actuators.
(b) Housed in single enclosure.

FIGURE 9 STATIC FEED ELECTROLYZER FLIGHT EXPERIMENT ELECTRICAL BLOCK DIAGRAM mounted in a subframe structure. The assembly will be tested in this structure and shipped in this structure. Upon receipt at this Kennedy Space Center (KSC), this frame will be then be mounted within the SPACEHAB rack. the experiment packaging concept is such that the experiment can be mounted in the very top portion of a rack and therefore allow a maximum availability of the remaining space within the rack. Figure 10 shows how the experiment can fit within the rack.

Experiment Interfaces

The overall experiment described in the sections above is illustrated by Figure 11. This figure shows the relationship between the components within the experiment and the interfaces of the experiment with the SPACEHAB. Key parameters of the overall experiment are illustrated by Table 3 and Table 4. Characteristics of the individual components are shown by Table 5.

Crew Interface

The Flight Experiment operation is initiated by crew action through the front panel of the Model 686 C/M I. The first action is to turn on power through a single switch. The next action is to initiate the experiment through the Touch Screen Interface Panel (TSIP). A single key pad is utilized. Each input requires two finger actuation to avoid accidental input of instructions. Foot restraints within the SPACEHAB allow for two-handed inputs through the TSIP.

Once initiated the experiment is totally automated. Operating data is displayed for crew monitoring on the TSIP. If changes in internal operating parameters are required, they can be made through the Onboard Computer Interface. Once the experiment is complete, crew action is required to turn off the power to the experiment.

Data collection for experiment evaluation is performed by the Model 686 C/M I. Data is stored in Electrically Erasable and Programmable Memory (Flash) and on a hard disk drive.

Mission Test Plan

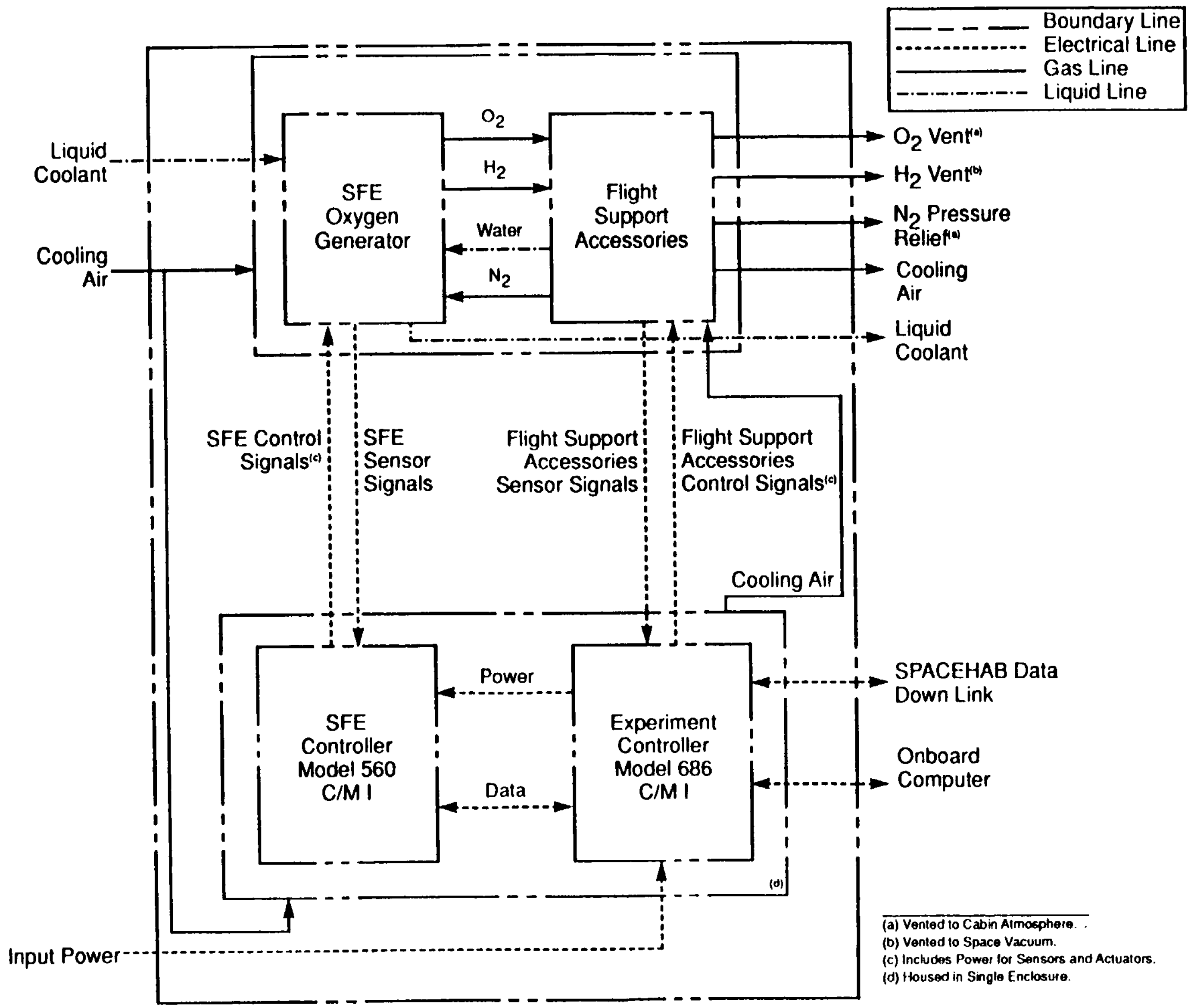
The objectives of the overall program require that the test plan generate a wide spectrum of microgravity test data for comparison against earth-based testing. The comparison of this data is to be the basis of evaluating the readiness of SFE technology for space missions and/or identifying modifications to achieve this readiness.

For a test program to meet the required objectives, it must demonstrate two things. They are:

1. Efficient function in microgravity and
2. Tolerance to shutdown - both planned and unplanned.

If failures occur, it must also provide sufficient data to allow future resolution of the failure.

The proposed mission test plan is shown by Figure 12. As shown the experiment is based on a four-day test program with the ability to operate for an extra two days. Table 6 provides a detailed description of the tests to be performed.



(a) Vented to Cabin Atmosphere.
(b) Vented to Space Vacuum.
(c) Includes Power for Sensors and Actuators.
(d) Housed in Single Enclosure.

FIGURE 11 INTERFACE BLOCK DIAGRAM

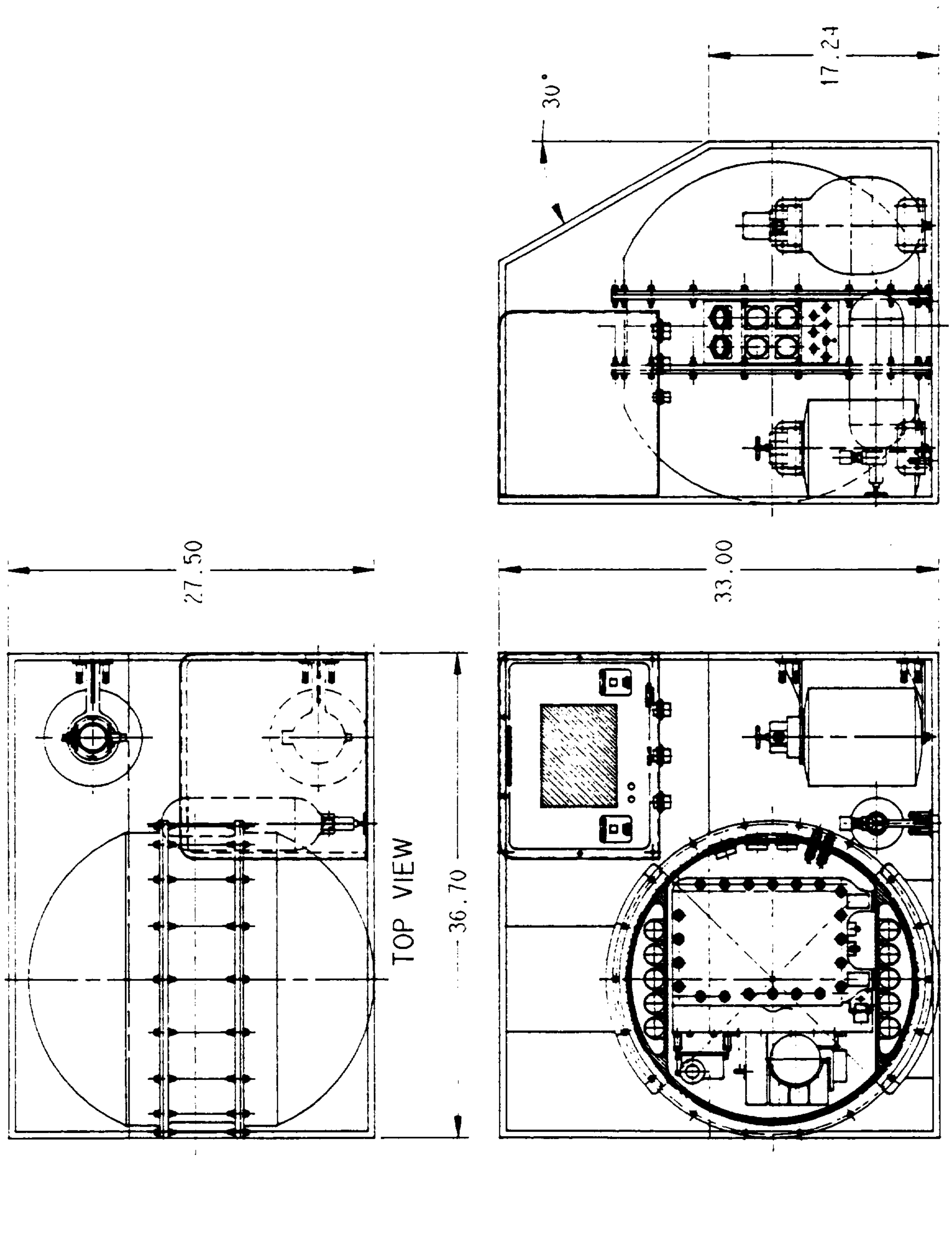


FIGURE 10 SFE FLIGHT EXPERIMENT PACKAGING IN SPACEHAB DOUBLE RACK

TABLE 3 SFE FLIGHT EXPERIMENT CHARACTERISTICS

Weight, lb	300
Dimensions (WxHxD), in	36.7 x 34.0 x 27.5
Volume, $ft^{(3)}$	19.9
Heat Load, W	250 to 600
Operating Temperature, F	130 to 150
Operating Pressure, psig	15 to 75
Current Density, $Amps/ft^2$	120 to 160
No. of 0.25 ft^2 Cells	5
O_2 Production Rate, lb/day	1.40 to 1.86
Water Consumption Rate, lb/day	1.57 to 2.10
Duty Cycle	53 min On, 37 min Off

TABLE 4 SFE FLIGHT EXPERIMENT NOMINAL INTERFACE REQUIREMENTS

Electrical Power (28 VDC), W	600
Coolant (Water)	
Flow Rate, lb/hr	55
Temperature, F	≤ 90
Pressure, psig	≥ 10
Temperature Rise, F	< 5
Coolant (Air)	
Flow Rate, cfm	30-TBD
Temperature, F	65-80
Pressure, psig	TBD
Temperature Rise, F	TBD
O_2 Vent, lb/hr[(a)]	0.058
H_2 Vent, lb/hr[(b)]	0.007
H_2O Supply	Self-Contained in Experiment
N_2	Self-Contained in Experiment
Data Acquisition/Storage	Self-Contained in Experiment
Data Communication	SPACEHAB data downlink
Test Operation/Crew Involvement	Minimal involvement associated with set-up, activation and deactivation of flight experiment via Model 686 controller or PGSC.[(c)]
Tools	None required

(a) Product O_2 vented to cabin.
(b) Venting to flight vehicle vacuum interface or equivalent.
(c) Payload General Support Computer (PGSC).

TABLE 5 SFE FLIGHT EXPERIMENT COMPONENT CHARACTERISTICS AND PERFORMANCE SUMMARY

Component Name	Wet Weight, lb[b]	Power, W[a]		Heat Load, W[a]		Envelope, in.
		Normal	Standby	Normal	Standby	
SFE Subsystem						
Electrolysis Module Assembly	67.4	271	0	27	0	9.8 x 10.5 x 15.4
Fluids Control Assembly	29.1	26	4	26	4	6.3 x 8.5 x 11.8
Pressure Control Assembly	12.0	2	2	2	2	4.1 x 4.5 x 12
Thermal Control Assembly	33.8	52	52	52	52	4.8 x 7.3 x 10.5
Triple Redundant H_2-in-O_2 Sensor Assembly	0.62	2	2	2	2	2.1 x 2.5 x 3.4
Triple Redundant O_2-in-H_2 Sensor Assembly	0.62	2	2	2	2	2.1 x 2.5 x 3.4
Model 560 C/M I	36.4	86	43	86	43	(c)
Cable Assemblies	6.0	0	0	0	0	--
Total:	185.9	441	105	197	105	
Experiment Support Hardware						
Water Supply Assembly	14.8	2	2	2	2	6.0 Dia x 12.1
N_2 Supply Assembly	7.3	2	2	2	2	4.0 Dia x 23.75
H_2 Gas Sample and Vent Assembly	1.5	0	0	0	0	2.0 x 7.0 x 8.0
O_2 Gas Sample and Vent Assembly	1.5	0	0	0	0	2.0 x 7.0 x 8.0
Cooling Fan Assembly[d]	3.0	100	100	100	100	--
Model 686 C/M I	21.1	46	46	46	46	(c)
Cable Assemblies	6.0	0	0	0	0	--
SFE Enclosure	37.7	2	2	2	2	24.0 Dia x 30.0
Nitrogen Booster Tank	3.2	0	0	0	0	--
Mounting Brackets	18.0	0	0	0	0	
Total:	114.1	152	152	152	152	
Total Experiment:	300.0	593	257	349	257	33.0 x 36.7 x 27.5

(a) While operating during cyclic operation involving 53 min. of O_2 generation in Normal and 37 min. in Standby.
(b) Initial launch configuration, including liquid inventories.
(c) Model 560 C/M I and Model 686 C/M I in a single enclosure 12.1 x 15.63 x 14.1 (H x W x D) in.
(d) Fan to be supplied via McDonnell Douglas specification. Parameters are estimated.

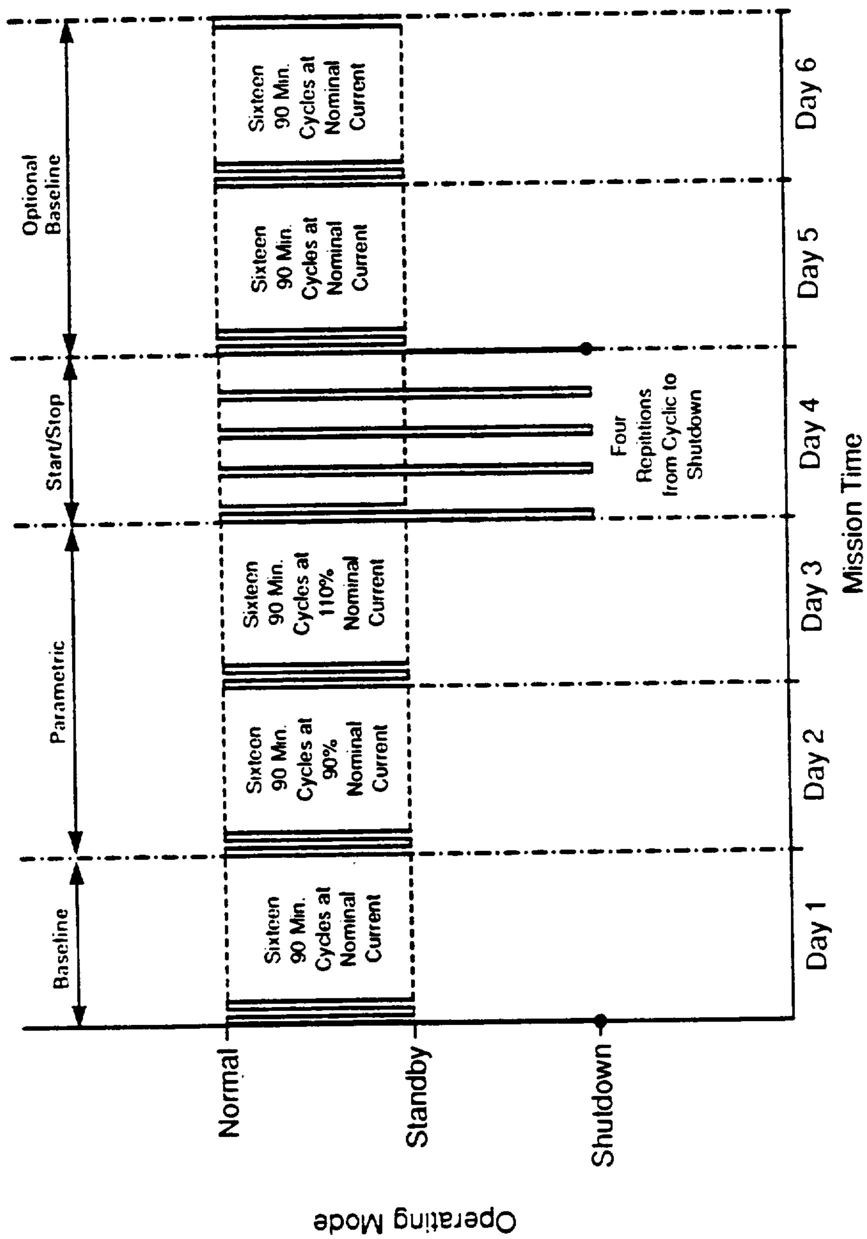


FIGURE 12 MISSION PROFILE

Efficient Operation: Demonstration of efficient operation is achieved by three full days of operation at different rates. If this data matches or exceeds earth-based data, the SFE can be said to be capable of operating successfully in microgravity.

Tolerance to Shutdown: The first three days of testing will demonstrate 48 transitions from Standby to Normal mode. If there is no deterioration over this period, it can be strongly argued that the design handles multiple transitions well. The fourth day will demonstrate the ability of the SFE to tolerate unplanned transitions to Shutdown, like those that would result from a power failure. Four simulated unplanned transitions will be implemented. Successful operation following these transitions will demonstrate the required tolerance.

Software

Software for the SFE Flight Experiment is separated into two packages. The first is for the Model 560 C/M I which controls the SFE portion of the experiment. The second is for the Model 686 C/M I which controls the FSA portion of the experiment and provides overall experiment sequencing and interface communication. The total software package provides for operation of the SFE in the modes shown by Figure 13. Figure 13 also shows the allowable mode transitions. The operating modes are described by Table 7. Figure 14 provides a Software Block Diagram describing the software configuration. The design of each software package is described below.

Model 560 C/M I Software

The SFE Flight Experiment Software for the Model 560 C/M I controller consists of an Operating System and an Application Specific Code. All software is developed using Programming Language for Microprocessors (PL/M). However, some assembly language coding is also done.

Model 560 C/M I Operating System Software. The Operating System software is to be utilized in the Model 560 C/M I's Life Systems' proven Series 400 Operating System. This operating system has been used extensively in Life Systems' Space Station hardware development work. The Series 400 Operating System demonstrated experience includes use in the Environmental Control and Life Support System Flight Experiment (EFE). It will also be utilized in the In-Space Technology Experiment Program (IN-STEP) Electrolysis Performance Improvement Concept Study (EPICS) Flight Experiment. Figure 15 illustrates the Series 400 Operating System.

The Operating System will perform the following functions:

1. Perform Intra-experiment Communication: The Model 560 C/M I will communicate with the Model 686 C/M I sending data and receiving commands (OS10.0).

2. Perform Transitions: This involves executing a sequence of steps to change the operating mode of the system, monitoring the transition progress and updating the system status to reflect the transition mode (OS5.0).

3. Perform Control Loops: This function is responsible for monitoring the states of the SFE components and performing actuator operations as required. The monitoring of the

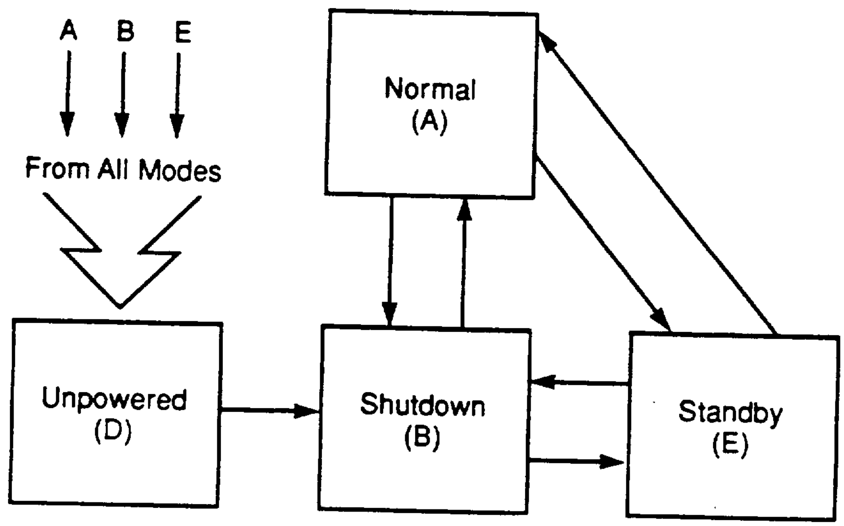
TABLE 6 TEST PLAN DEFINITION

Day	Test Element	Test Description
1	Baseline	• Operation in a cyclic mode, generating O_2 and H_2 during 53 min of the sunlit portion of each orbit followed by idling in Standby for 37 min of the shade time of each orbit. • All parameters are baseline values.
2	Parametric, Low	• Operation in a cyclic mode, generating O_2 and H_2 during 53 min of the sunlit portion of each orbit followed by idling in Standby for 37 min of the shade time of each orbit. • Oxygen generation at 90% of the nominal, all other parameters at baseline values.
3	Parametric, High	• Operation in a cyclic mode, generating O_2 and H_2 during 53 min of the sunlit portion of each orbit followed by idling in Standby for 37 min of the shade time of each orbit. • Oxygen generation at 110% of the nominal, all other parameters at baseline values.
4	Start/Stop	• Four repetitions of transitioning from Normal to Shutdown, and transitioning from Shutdown to Normal followed by three 53 min Normal/37 min Standby cycles and transitioning to Shutdown. • All parameters at baseline values for each mode.

continued-

Table 6 - continued

Day	Test Element	Test Description
5	Optional (Baseline)	• Operation in a cyclic mode, generating O_2 and H_2 during 53 min of the sunlit portion of each orbit followed by idling in Standby for 37 min of the shade time of each orbit. • All parameters at baseline values.
6	Optional (Baseline)	• Operation in a cyclic mode, generating O_2 and H_2 during 53 min of the sunlit portion of each orbit followed by idling in Standby for 37 min of the shade time of each orbit. • All parameters at baseline values



- 4 Modes
- 3 Operating Modes
- 10 Mode Transitions
- 7 Programmable, Allowed Mode Transitions

FIGURE 13 MODES AND TRANSITIONS

TABLE 7 MODE DEFINITIONS

Mode (Code)	Definitions
Normal (A)	SFE Oxygen Generator: The SFE is performing its function of generating O_2 and H_2 at the experiment specified rate. Experiment Support Hardware: The O_2 and H_2 Gas Sample Assemblies are collecting samples as defined by the test protocol. The SPACEHAB Coolant Package is providing liquid coolant to the SFE. The Experiment Support Controller is in charge of simulating the light - dark cycle of the orbit and collecting and storing data. Mode Initiation: • Automatic mode Transition from Standby based on completion of the dark portion of the simulated orbit (initiated by the experiment controller). • Crew Initiation through the Experiment Support Controller crew interface from Standby or Shutdown.

continued-

Table 7 - continued

Mode (Code)	Definitions
Standby (E)	SFE Oxygen Generator: The SFE is ready to generate O_2 and H_2. The SFE O_2 generator is at its operating pressure and temperature. Experiment Support Hardware: Experiment support hardware is active. All interfaces are available. Make-up water and purge/pressure-maintaining-N_2 are available to the SFE. The Experiment Support Controller is in charge of simulating the light-dark cycle of the orbit and collecting and storing data. The Coolant Supply Package is providing liquid coolant to the SFE. Mode Initiation: • Automatic mode transition from Normal based on completion of the light portion of the simulated orbit (initiated by the experiment support controller). • Crew initiation through the experiment support controller interface from either Shutdown or Normal.

continued-

Table 7 - continued

Mode (Code)	Definitions
Shutdown (B)	SFE Oxygen Generator: The SFE is not generating O_2 or H_2 and is at or approaching ambient temperature and pressure. The SFE is powered and all sensors are working. All actuators are off. Experiment Support Hardware: Support hardware supplied interfaces are available but are inactive. The Experiment Support Controller is powered and all sensors are active. No support hardware actuators are active except the Cooling Fan Assembly. Liquid coolant from the SPACEHAB Coolant Package is not required.. Mode Initiation: • Crew initiated mode transition from Normal via experiment controller crew interface. • Crew initiated mode transition from Standby via experiment controller crew interface. • Automatically initiated mode transition from Normal or Standby for any alarm condition generated by an out-of-range sensor value. • Power-On-Reset (POR) from Unpowered mode.

continued-

Table 7 - continued

Mode (Code)	Definitions
Unpowered (D)	SFE Oxygen Generator: No electrical power is applied to the SFE. Actuator positions cannot be verified. No H_2 or O_2 is being generated. Experiment Support Hardware: No electrical power is applied to the experiment support hardware. Actuator positions cannot be verified. No liquid coolant is required from the SPACEHAB Coolant Package. Mode Initiation: • Manual removal of elctrical power, or • Electrical power failure

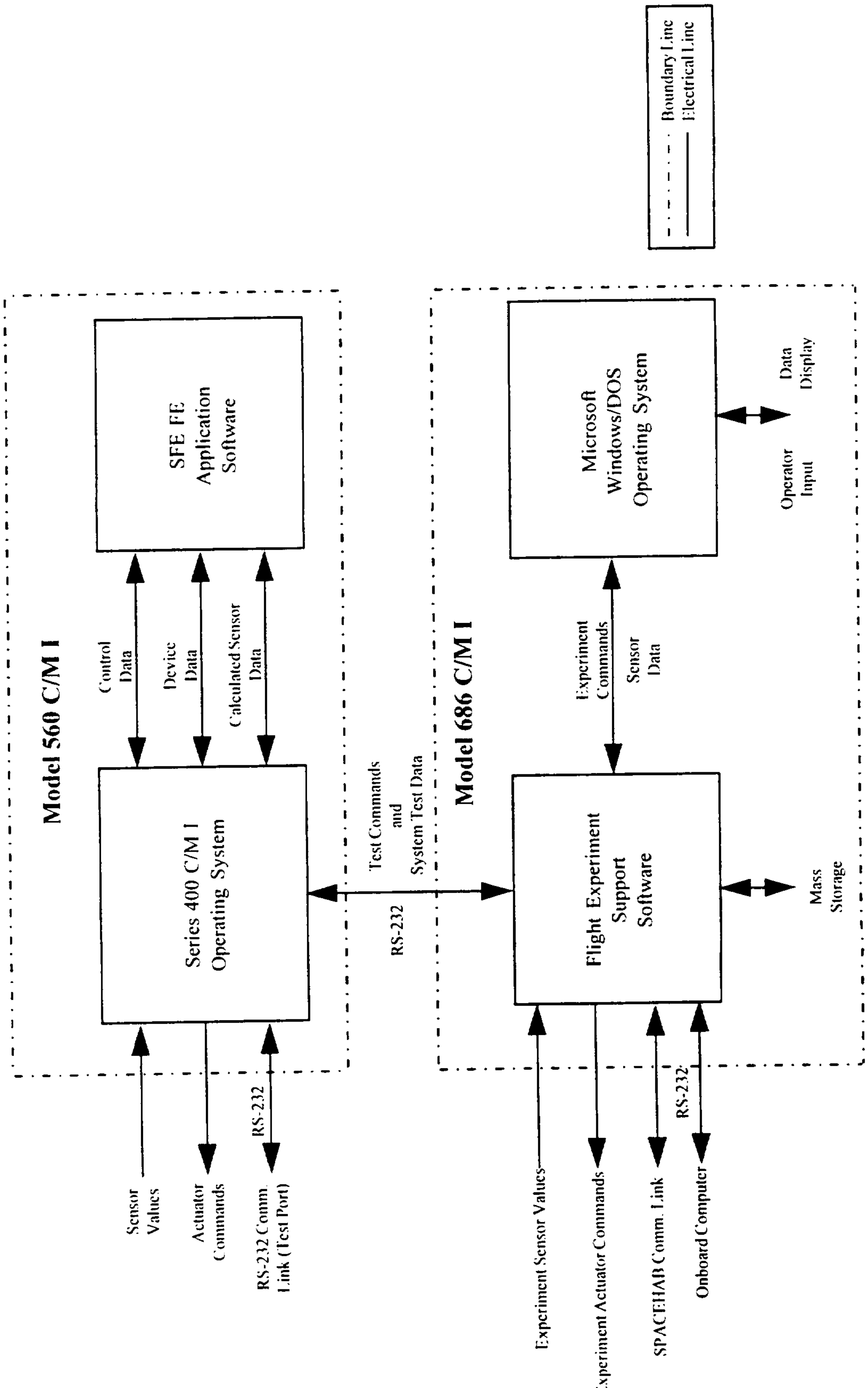
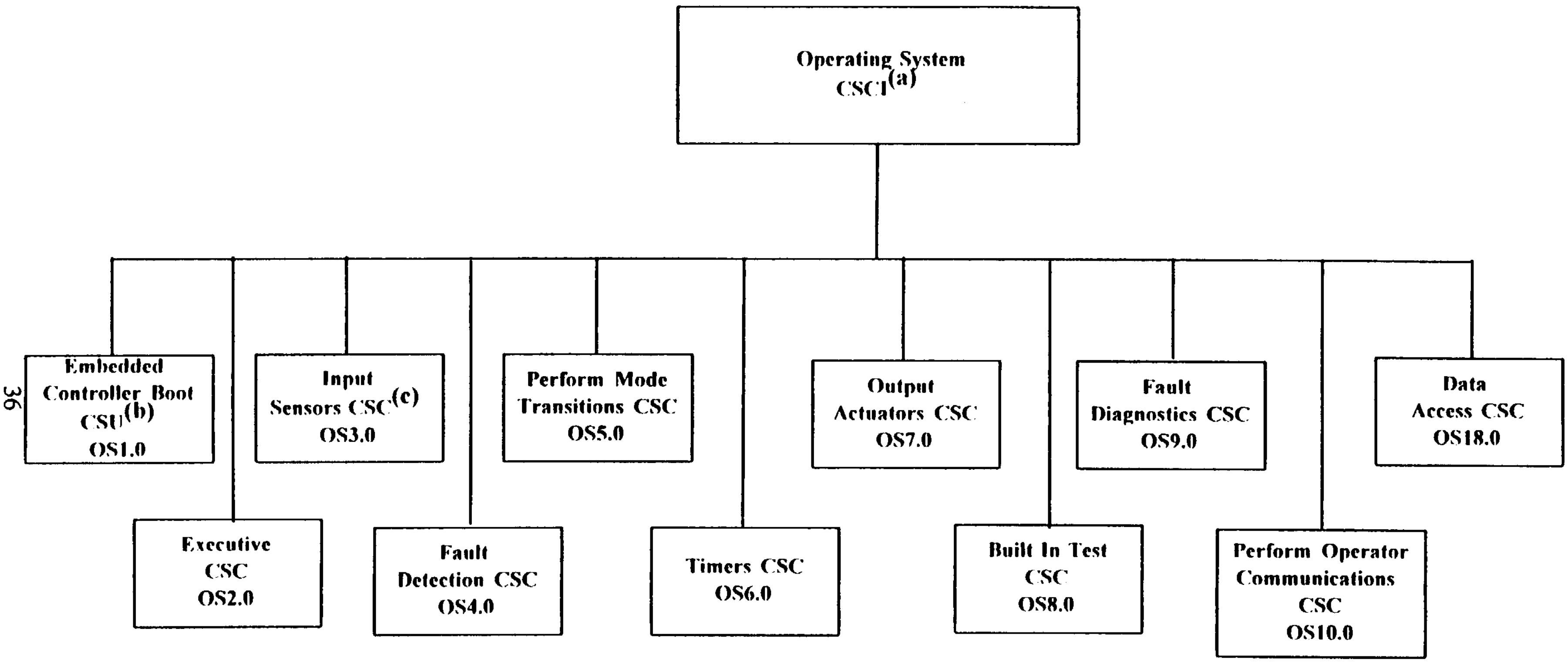


FIGURE 14 SOFTWARE BLOCK DIAGRAM



(a) Computer Software Configuration Item.
(b) Computer Software Unit.
(c) Computer Software Component.

FIGURE 15 SERIES 400 OPERATING SYSTEM SOFTWARE component involve reading sensor values and comparing them to high and low setpoint values and performing appropriate actions. The control algorithms are defined in the Application Specific portion of the software.

4. Diagnose Faults: Fault diagnosis is accomplished by two major functions, namely, Fault Detection and Fault Isolation. Fault Detection is accomplished by comparison of sensor signal values with predetermined setpoint values for normal, warning and alarm conditions. Fault Isolation identifies the cause of the failure of the system. Data will be collected to allow manual fault isolation. Automatic fault isolation will not be incorporated (OS4.0, OS9.0).

5. Input Sensors: This function brings the analog and digital signals from the subsystem hardware through the generic signal conditioning to the C/M I and converts them into a form readable by the computer (OS3.0).

6. Output Actuators: Based on the states of the various ORUs, output signals are sent to the subsystem mechanical assembly from the C/M I through the signal conditioning (OS7.0).

7. System Service Handling: This function will provide special system services like hardware and software initialization, internal timer updates, power failure handling and arithmetic routines (OS1.0, OS2.0, OS6.0, OS8.0).

8. Data Accessing: This function is responsible for providing read/write access to System Data Tables, Sensor Data Stores and Actuator Data Stores (OS18.0).

Model 560 Application Software. Figure 16 illustrates the Model 560 Application Software. The Application Specific Code consists of:

1. Tables used by the Mode Transition Function in the Operating System (AS4.0).

2. Setpoint tables for the different operation modes for the purpose of fault detection and control of the system (AS4.0).

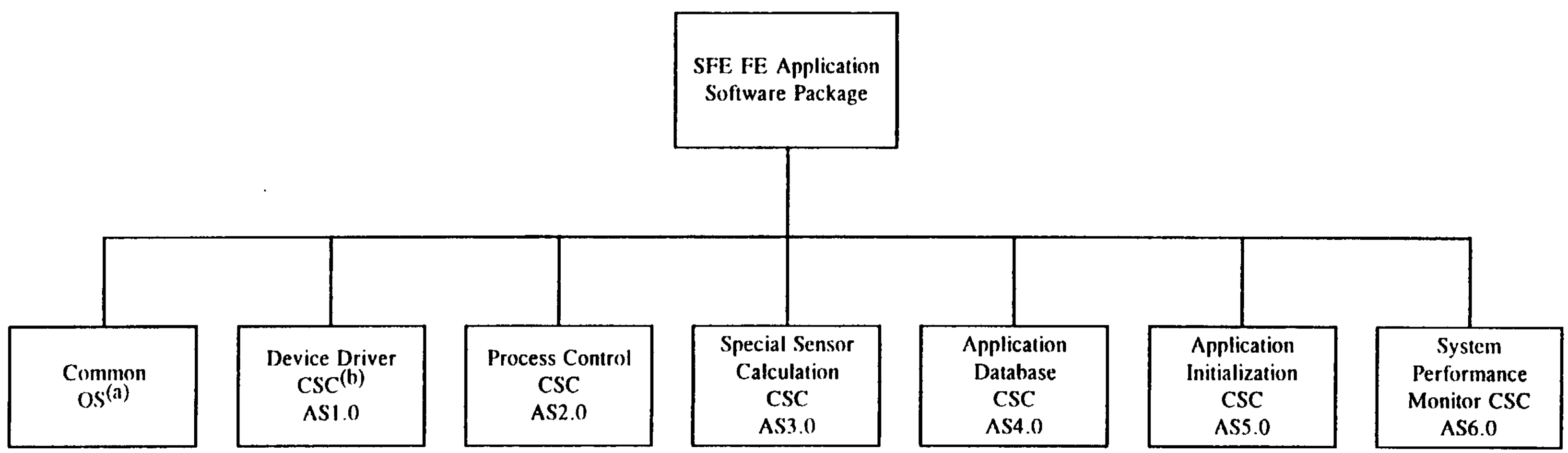
3. Definitions for the different control algorithms used in the system (AS2.0).

4. Definitions that provide control for devices in the system like pumps, valves and motors (AS1.0).

5. Routines for calculating parameters not directly measured by the mechanical subsystem that are required as sensor values for the real time control of the system (AS3.0).

6. Application Initialization: This function is responsible for setting the control loops and device drivers to a predetermined initial stable state so as to provide a valid starting point for the process (A5.0).

7. System Performance Monitor: This software component (not active in the Flight Experiment) is responsible for carrying out an on-line evaluation of the performance of the system (AS6.0).



(a) Operating System.
(b) Computer Software Component.

FIGURE 16 MODEL 560 C/M I APPLICATION SOFTWARE

Model 686 C/M I Software

The SFE Flight Experiment support software for the Model 686 C/M I consists of an Operating System, general routines to instruct the Operating System to perform certain low level functions and Application Specific Code. The general routines and most of the Application Specific Code are developed in C. The Crew Interface is developed in Visual Basic running under Microsoft Windows.

Model 686 Operating System Software. The Operating System used is Microsoft Disk Operating System (MS-DOS). Figure 17 illustrates the Model 686 Operation System software. Its functions include:

1. Perform Intra-Experiment and External Communication: The Model 686 C/M I communicates with the Model 560 C/M I for the purpose of receiving data and issuing commands. There is also a provision for external communication to enable the operator to issue commands to the system and obtain a visual feedback of the state of the system. The Model 686 C/M I is also responsible for downlinking of data (OS7.0).

2. Read Sensors: This function reads the analog and digital signals from the FSA subsystem hardware through the generic sensor signal conditioning to be interpreted by higher level routines (OS3.0).

3. Output Actuators: Output signals based on decisions made at a higher level are sent to the FSA subsystem hardware through the signal conditioning (OS6.0).

4. System Service Handling: This involves handling of services like hardware and software initialization, internal timer updates and power failure handling (OS2.0, OS5.0).

5. Data Logging/Storage: This refers to the allocation of the appropriate space and functions to store data retrieved from the Flight Experiment and the FSA hardware (OS4.0).

6. Data Access: This function provides read/write access to the Flight Support Sensor and Actuator Tables (OS15.0).

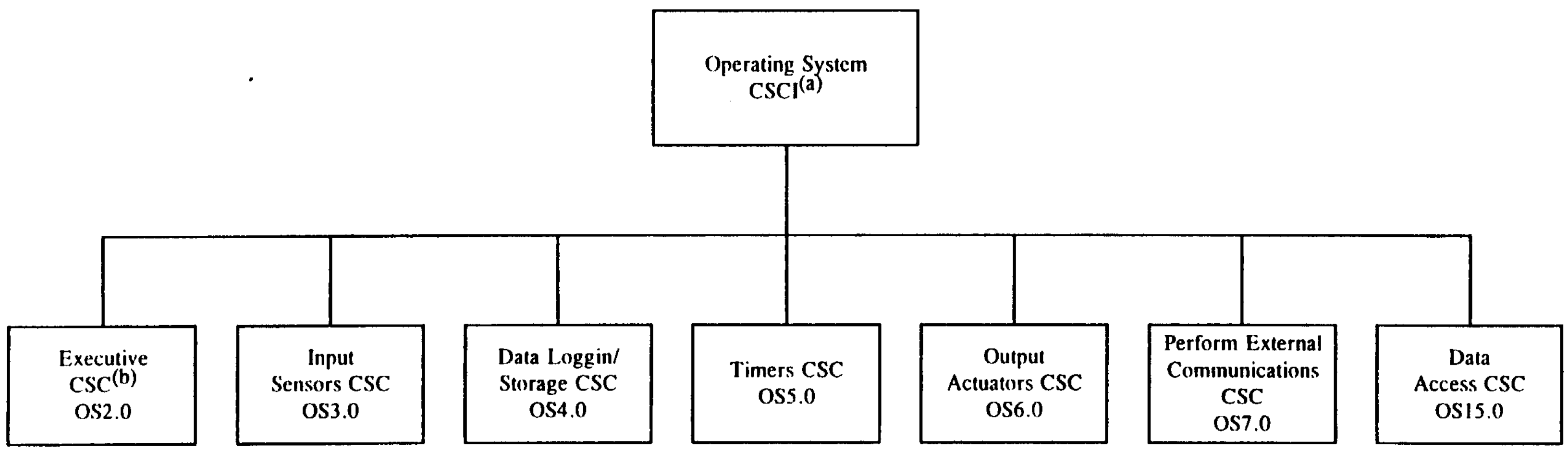
General routines will be developed to instruct the Operating System to carry out certain low level operations. The functions provided by these general routines are:

1. Perform Control Loops: This function monitors the states of the various subsystems in the FSA and instructs the Operating System to perform new actuator outputs that may be required.

2. Input Sensors: This function converts the signals read in by the Operating System and converts them to a form readable by the computer.

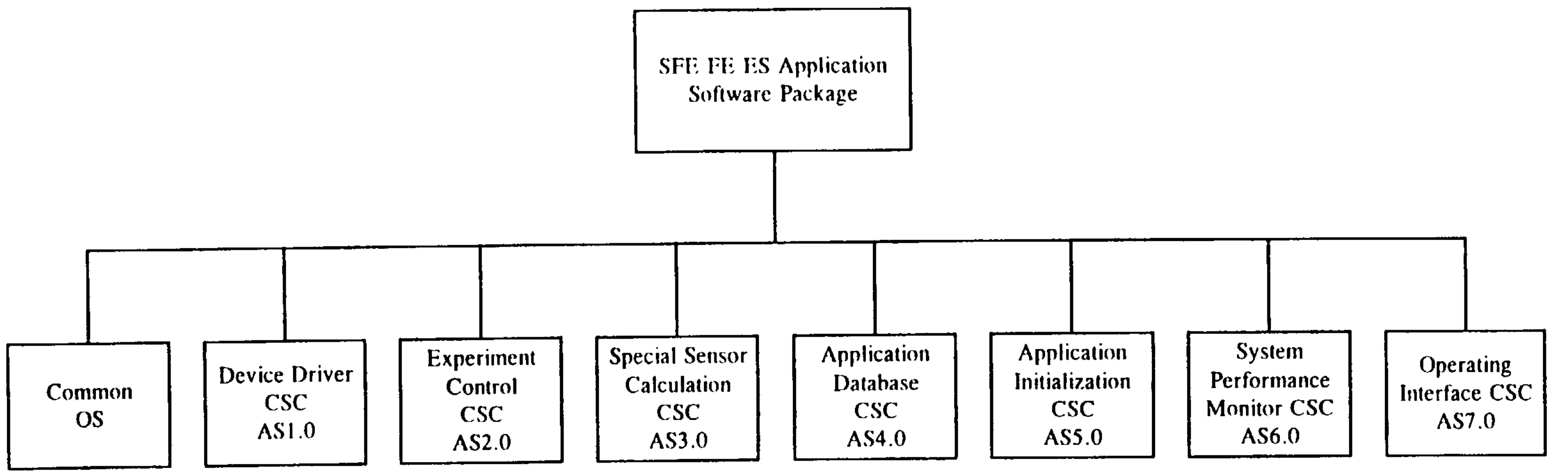
Model 686 Application Software. Figure 18 illustrates the Model 686 Application Software. The Application Specific Code consists of:

1. Setpoint tables for the sensors in the FSA for real time control of the FSA (AS4.0).



(a) Computer Software Configuration Item.
(b) Computer Software Component.

FIGURE 17 MODEL 686 C/M I OPERATING SYSTEM SOFTWARE



(a) Operating System.
(b) Computer Software Component.

FIGURE 18 MODEL 686 C/M I APPLICATION SOFTWARE

2. Definitions for the sequential execution of predetermined steps of the experiment and the control algorithms (if necessary) used in the FSA (AS2.0).

3. Definitions to provide control for devices in the FSA like pumps, valves and motors (AS1.0).

4. Routines for calculating parameters not directly measured by the FSA that are required as sensor values for control of the FSA subsystems (AS3.0).

5. Operator Interface: This enables the operator to issue commands to the Flight Experiment and Experiment Support hardware. The interface is developed in Visual Basic. Through this interface, the operator can also obtain updated information about he sensor values, actuator values and the state of the system and its various components. Input to this interface is provided by means of touch through a touchscreen LCD display. To prevent any unwanted action due to accidental touching of the display, a two-finger actuation is required to activate the ability to issue commands. Extensive menus are provided to enable the operator to obtain considerable information about the system. It is also possible to start the test from an arbitrary but valid point in the sequence (AS7.0).

6. Application Initialization: This function is responsible for placing the FSA in an initial state (AS5.0).

7. System Performance Monitor: This software component (not active in the Flight Experiment) is provided an online evaluation of the FSA performance (AS6.0).

DESIGN DOCUMENTATION

The product of the Preliminary Design Phase of the program is an experiment design that will be the basis for the Phase C/D portion of the program. The design product is documented in three ways. They are design drawings, design documents and a high fidelity mockup. Each form of documentation is described below.

Design Drawings

For the PDR, Form, Fit and Function drawings were made for each ORU. From these drawings a rack packaging drawing was prepared. Design drawings produced are defined below:

Drawing No.	Title
D17001	SFE Flight Experiment Mechanical Schematic with Sensors
D17008	SFE Flight Experiment Mechanical Subassembly
D17010	Fluids Control Assembly
D17011	Electrochemical Module Assembly
D17012	Thermal Control Assembly
D17013	Pressure Control Assembly
D17014	Triple Redundant H_2-in-O_2 Sensor
D17015	Triple Redundant O_2-in-H_2 Sensor

Drawing No.	Title
D17022	N_2 Supply Assembly
D17023	Water Supply Assembly
D17024	Vent Hardware Assembly
D17025	Model 686 Control/Monitor Instrumentation (C/M I)
D17026	SFE Enclosure
D17027	Cooling Air Fan
D17028	Nitrogen Booster Tank
D17038	SFE Subrack Assembly

A complete set of the above drawings can be found in the PDR Data Package (TR-1723-18-2).

Design Documentation

The final approval of the SFE Flight Experiment for flight will require documentation of the analyses performed to ensure its readiness. In all cases these documents will be finalized during the Phase C/D portion of the program. However, many of these have been initiated during this phase of the program and are completed to the extent possible. Design documents prepared during the Preliminary Design are defined below.

Trade Studies and Rationale for Flight Experiment Configuration

The Trade Studies and Rationale for Flight Experiment Configuration Report (TR-1723-4) documents and the five (5) trade studies that were prepared to define the experiment.

Technical Requirements Document

The Technical Requirements Document (TRD), TR-1723-5, defines the experiment on the basis of its needs, objectives and means by which the experiment objectives are to be achieved.

Interface Control Document

The Interface Control Document (ICD), TR-1723-6, defines the interfaces (fluid, structural, crew, electrical, data) of the experiment as they are currently known. This document will provide the means of transmitting interface data to McDonnell Douglas for preparation of their ICD for flight.

Safety Hazard Analysis

The Safety Hazard Analysis (SHA), TR-1723-8, presents an analyses of the hazards identified that are associated with the SFE Flight Experiment. Data contained in this document will support the future program safety reviews.

End Item Specification

The End-Item Specification, SS-0041, is a B1 Prime Item Development Specification prepared per the requirement of MIL-STD-490A. The specification defines the initial basis of how the Phase C/D program detailed design will be performed and how end-item verification will be achieved. It will be used by NASA to generate the final specification of the flight article.

Retrofit Kit Definition Document

The Retrofit Kit Definition Document, TR-1723-13, defines the means by which the experiment could be incorporated in the SPACEHAB, Spacelab or MIR flight vehicles.

Safety, Reliability and Quality Assurance Plan

The Safety, Reliability and Quality Assurance (SR&QA) Plan, TR-1723-14, defines Life Systems' plan for ensuring that the end-item experiment meets contract requirements.

Failure Modes and Effects Analysis

The Failure Modes and Effects Analysis (FMEA), TR-1723-15, defines how the experiment will react to failure and defines why it meets the requirements of the contract.

Critical Items List

The Critical Items List (CIL), TR-1723-16, takes the results of the FMEA and defines those items which require special consideration due to their criticality for safe operation.

Nonmetallic Materials List

The Nonmetallic Materials List, TR-1723-17, defines the document which will be used to document the nonmetallic materials to be utilized in the experiment. It will be completed during Phase C/D.

Preliminary Thermal Analysis Report

The Preliminary Thermal Analysis Report, TR-1723-23, presents an analysis of each component for its contribution to waste heat, the possibility of overheating and thermal impact on component performance to identify potential areas of concern that would require more rigorous analysis.

Preliminary Loads Analysis Report

The Preliminary Loads Analysis Report, TR-1723-24, presents an analysis of the force loads that the experiment will be subjected to in the SPACEHAB vehicle.

Preliminary Stress Analysis Report

The Preliminary Stress Analysis Report, TR-1723-25, documents the analyses to be performed in each component during the Phase C/D program.

A complete set of the above program documents can be found in the PDR Data Package (TR-1723-18-2).

High Fidelity Mockup

A key product of the Preliminary Design of the SFE Flight Experiment is the high fidelity mockup pictured in Figure 19. This mockup was fabricated based on the drawings listed in the Design Drawings section of this report. It illustrates the packaging plan and defines the envelope required.

PRELIMINARY DESIGN REVIEW

The PDR took place in two phases. The first phase was a review by representatives of NASA and Boeing of design data submitted by Life Systems prior to the PDR meeting. The second phase was review of the design as presented by Life Systems at the PDR. As a result of this process, Review Item Discrepancies (RIDs) were prepared. The two phases of the review and the resulting RIDs are discussed separately below.

Data Package Review

The preliminary design prepared by Life Systems was documented by the materials described in the Design Documentation section of this report. A complete compilation of this information was collected in the SFE Flight Experiment Preliminary Design Review Data Package, TR-1723-18-2. Materials contained in this data package that were defined to be "RIDable" by Marshall are defined by Table 8.

Preliminary Design Review Meeting

The PDR meeting was held at the Marshall Space Flight Center on March 15 and 16, 1995. The basis of this review was the Preliminary Design Review Presentation Package (TR-1723-18-3) which provided a means, by use of viewgraphs, to present and explain the SFE Flight Experiment design. The events of the meeting are summarized by the Meeting Minutes, TR-1723-18-4, dated March 29, 1995.

Review Item Discrepancies

As a result of the review process there were thirteen (13) RIDs defined. Table 9 provides a list of these RIDs. Following a review of the responses prepared by Life Systems, a RID Preboard Meeting was held at the Marshall Space Flight Center on April 12, 1995. As a result of this meeting it was determined that a Board Meeting would not be necessary and that Life Systems stated future course of action would be accepted for eventual RID closure.

CONCLUSIONS

The stated objectives of this Preliminary Design program effort were to:

1. Define an experiment to accomplish the overall program goals.
2. Develop and document a design through a PDR that can be efficiently implemented in hardware.

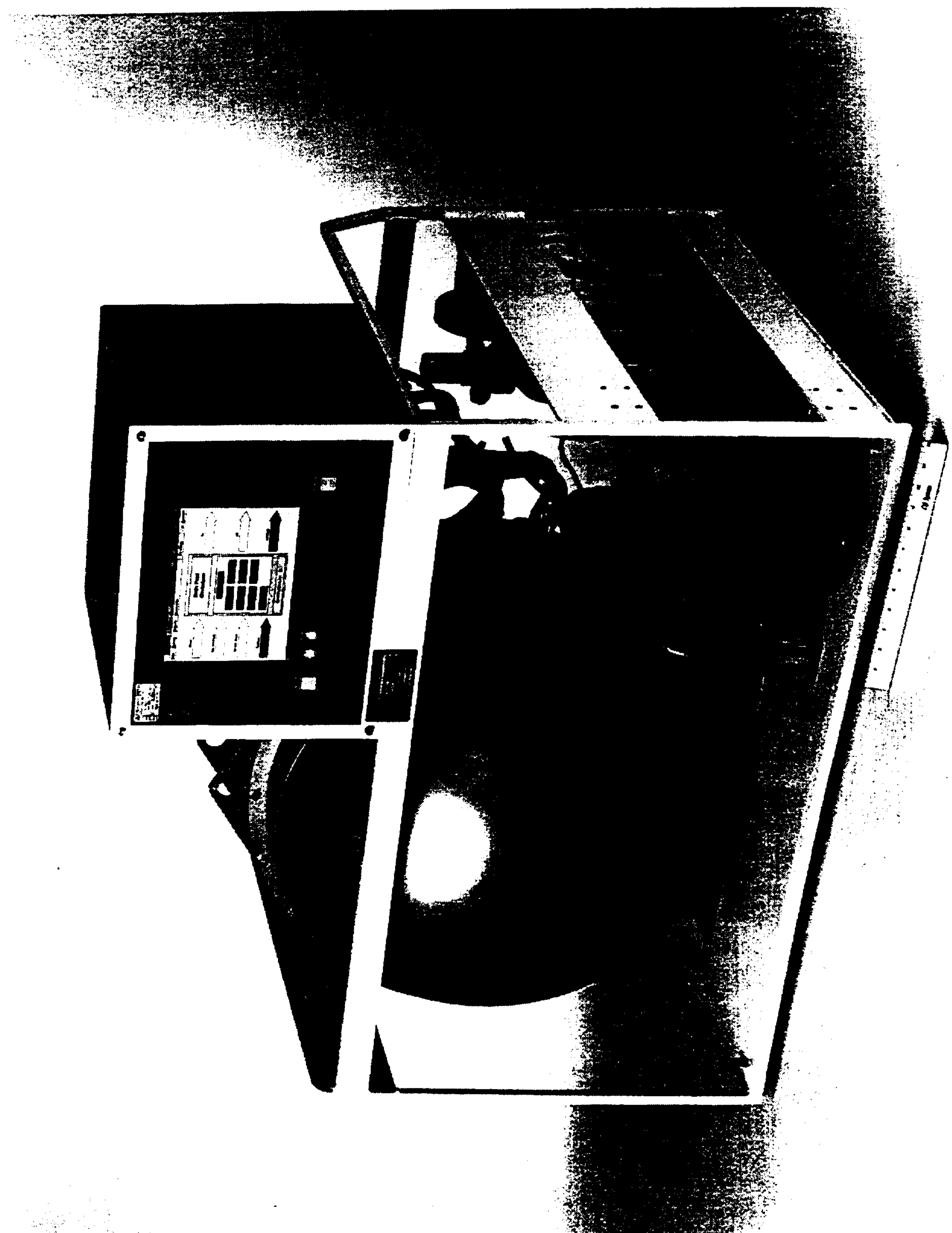


FIGURE 19 SFE FLIGHT EXPERIMENT MOCKUP

TABLE 8 SFE FLIGHT EXPERIMENT PRELIMINARY DESIGN REVIEW "RIDABLE" DOCUMENTS

- Preliminary Technical Document (TR-1723-5)
- Preliminary Interface Control Document (TR-1723-6)
- Layout Drawings[a]
- Preliminary Safety Hazards Analysis (TR-1723-8)
- Mechanical Schematic with Sensors (TR-1723-10)
- Assembly Drawings[a]
- Preliminary End-Item Specification (TR-1723-12)
- Retrofit Package Definition Document (TR-1723-13)
- Safety, Reliability and Quality Assurance Plan (TR-1723-14)
- Preliminary Failure Modes and Effects Analysis (TR-1723-15)
- Preliminary Critical Items List (TR-1723-16)
- Preliminary Metallic/Nonmetallic Materials List (TR-1723-17)
- Preliminary Thermal Analysis Report (TR-1723-23)
- Preliminary Loads Analysis Report (TR-1723-24)
- Preliminary Stress Analysis Report (TR-1723-25)

(a) Presented in Appendix 1 of the Data Package (TR-1723-18-2).

TABLE 9 STATIC FEED ELECTROLYZER FLIGHT EXPERIMENT
REVIEW ITEM DISCREPANCIES

RID No.	Description	Status
SFE-01	Insufficient Loads Analysis for PDR	(a)
SFE-02	Insufficient Stress Analysis for PDR	(a)
SFE-03	Insufficient Identification of Fracture Critical Parts for PDR	(a)
SFE-04	Insufficient Thermal Analysis for PDR	(a)
SFE-05	Inconsistent Identification of Critical Item	(a)
SFE-06	Inadequate Identification of the Causes and Controls of Identified Hazards	(a)
SFE-07	Specification Collector RID	(a)
SFE-08	Hydrogen Reference Pressure for PR2 (Single Barrier)	(a)
SFE-09	Hydrogen/Oxygen Differential Pressure Sensor (P2-Single Barrier)	(a)
SFE-10	Purge System Isolation	(a)
SFE-11	Discharge Through Rupture Disc	(a)
SFE-12	Pressurized Lines and Component Design Requirements	(a)
SFE-13	Single Barrier Separating Oxygen from Hydrogen (Cell Cores)	(a)

(a) Contractor response accepted. Final implementation of all design activities in Phase C/D of program.

Information included under the heading of Mission Test Plan presents the experiment plan defined to accomplish Objective No. 1. As described, this experiment plan will provide extensive data that, when compared to earth-based test data, will verify the readiness of SFE technology for application to ISSA or other long-duration missions.

Objective No. 2 was accomplished by the PDR described herein. At this review the design documentation was presented that, with resolution of open RIDs, was evaluated to be capable of performing the experiment test plan.

The successful implementation of the PDR shows that an SFE Flight Experiment can be implemented within the resource constraints of the available flight vehicles that will accomplish the goals of the program.

RECOMMENDATION

Information presented in this final report documents the design of an experiment and test hardware that when carried through to flight testing will accomplish the overall program goal of risk mitigation for the ISSA. Based on the successful conclusion of the Preliminary Design and successful demonstration of operation of SFE technology in cyclic mode of operation, it is recommended that the experiment proceed as planned into the second phase of the program which will culminate with flight testing of SFE technology in a microgravity environment.

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15. Supplementary Notes

16. Abstract

This document provides a description of the results of a program to prepare a Preliminary Design of a Flight Experiment to demonstrate the function of a Static Feed Electrolyzer (SFE) in microgravity. This report describes the test sequence to be performed and the hardware, Control/Monitor Instrumentation and software designs prepared to perform the defined tests. The purpose of the Flight Experiment is to significantly reduce the technical and programmatic risks associated with implementing a SFE based Oxygen Generator on board the International Space Station Alpha.

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